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EP 0220032 A2

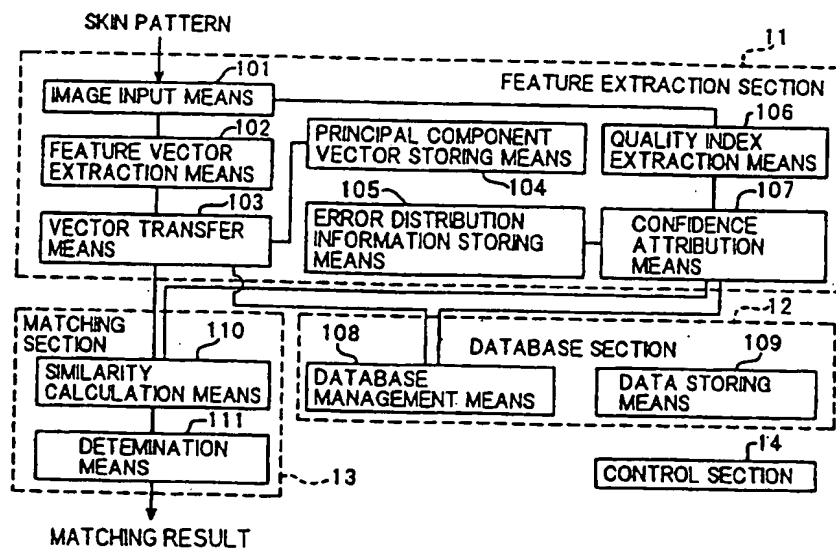
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(54) Fingerprint matching

(57) An image feature extractor (11) has a feature vector extraction means (102) for extracting a feature vector from a pattern image, a quality index extraction means (106) for extracting quality index information of the pattern image, an error distribution information storing means (105) wherein error distribution information representing correlation between error distribution of the feature vector and the quality index information is prepared, and a confidence attribution means (107) for obtaining confidence estimation information referring to the error distribution information retrieved with the quality index information. An image feature matching system identifies feature information of an image pattern extracted by the image feature extractor (11) by comparing it to registered feature information.

FIG.1



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FIG. 1

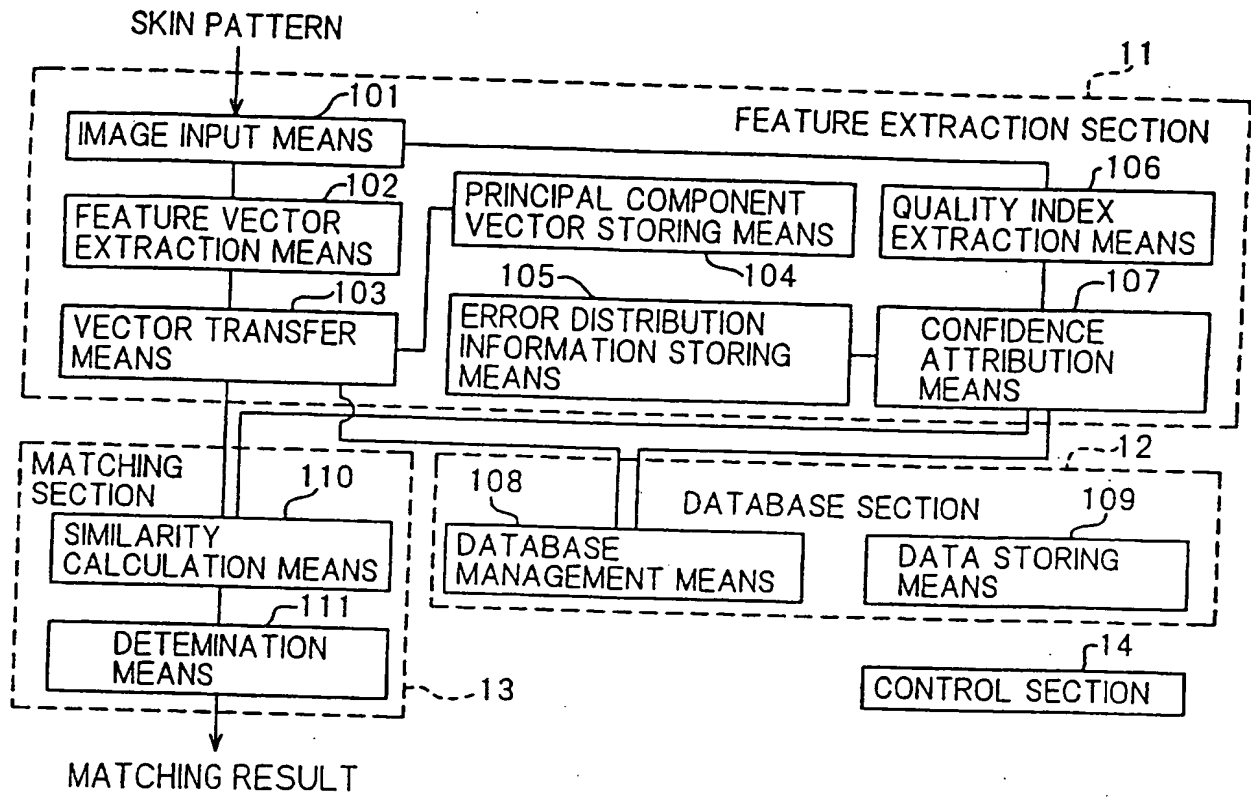


FIG. 2

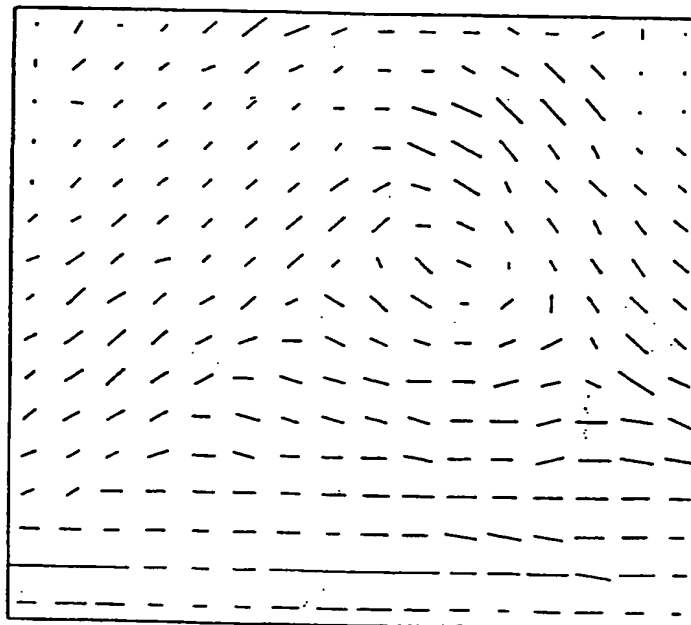


FIG. 3

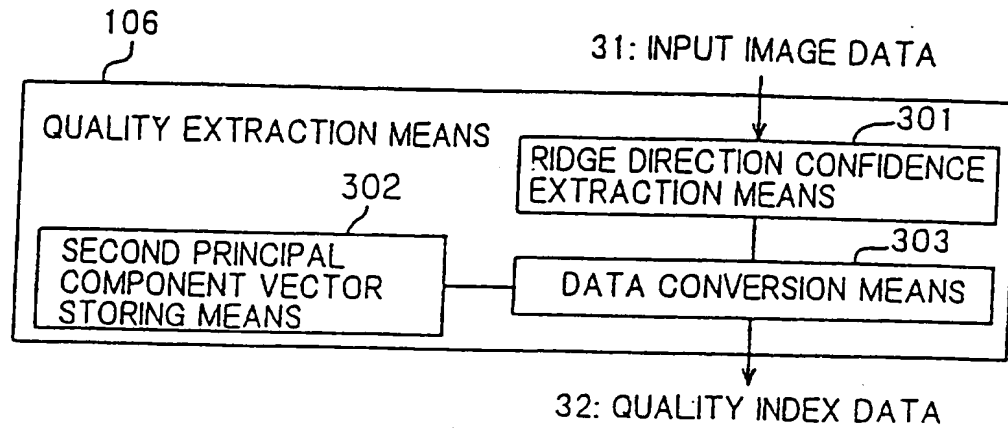


FIG. 4

	$Q_1 < \alpha_1$	$\alpha_1 \leq Q_1 < \alpha_2$...	$\alpha_{n-1} \leq Q_1$
Q_1	$\sigma_{1.1}$	$\sigma_{1.2}$...	$\sigma_{1,n}$
Q_2	$\sigma_{2.1}$	$\sigma_{2.2}$...	$\sigma_{2,n}$
\vdots	\vdots	\vdots	\ddots	\vdots
Q_L	$\sigma_{L.1}$	$\sigma_{L.2}$...	$\sigma_{L,n}$

FIG. 5

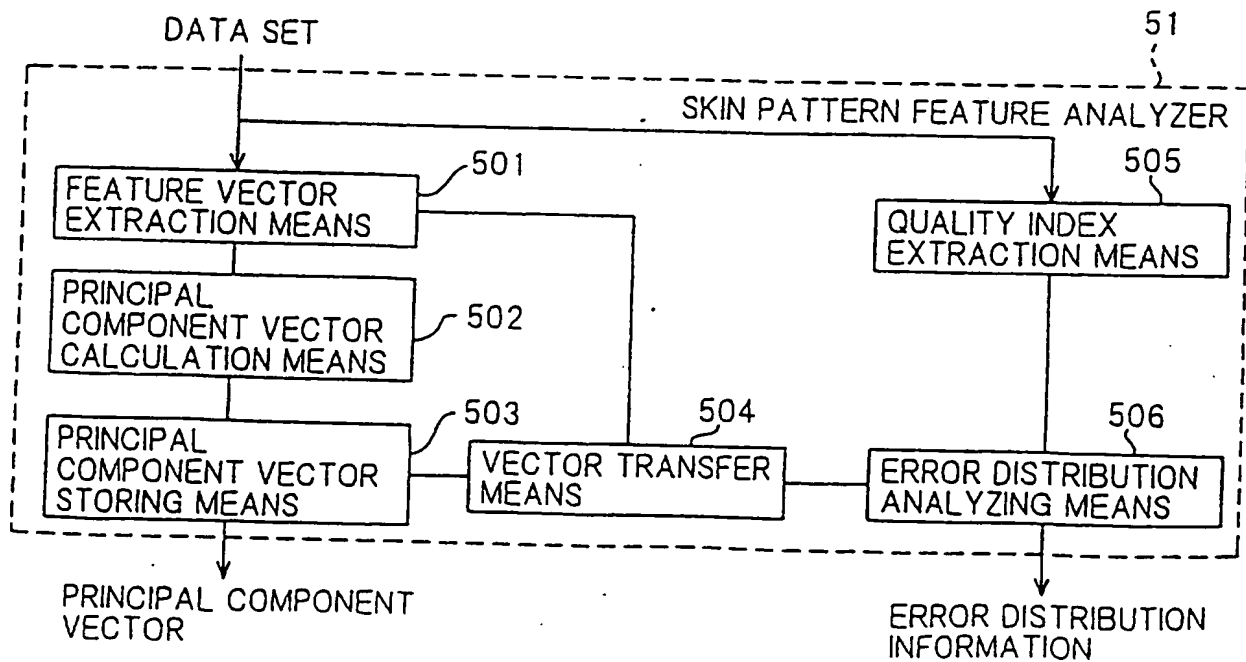
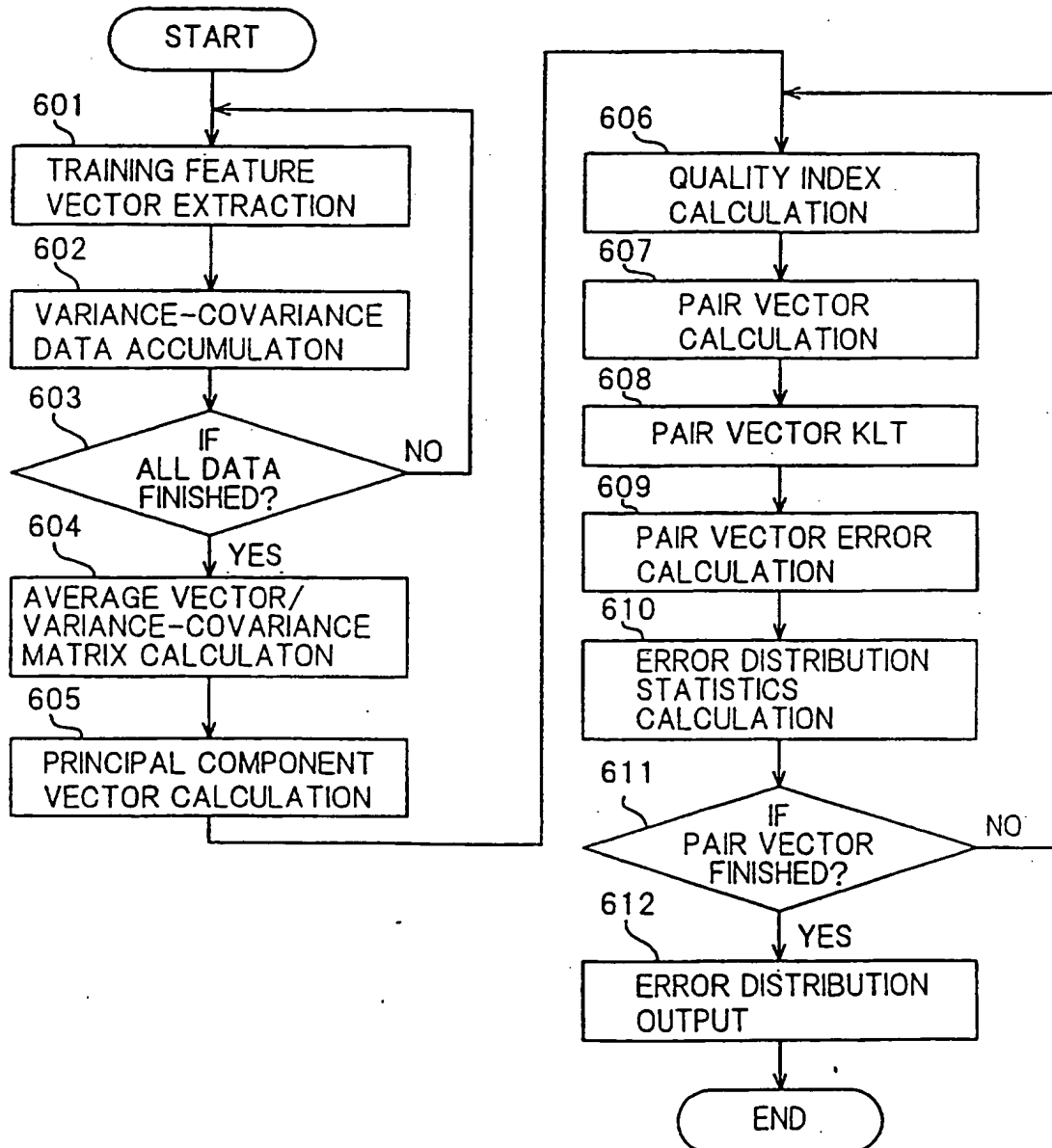


FIG. 6



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FIG. 7

STANDARD DEVIATION
OF ERRORS

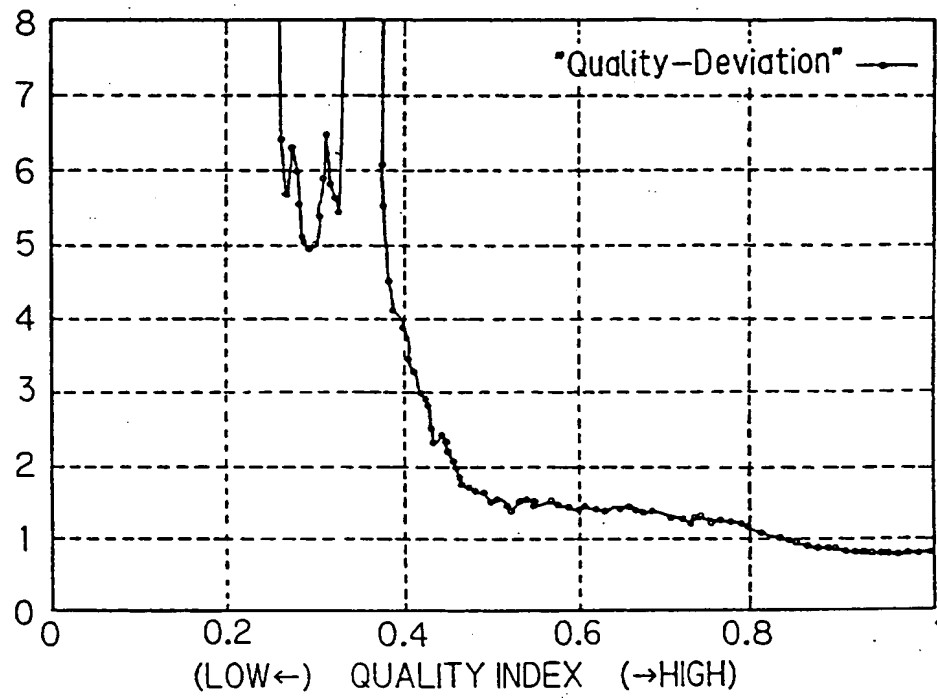


FIG. 8

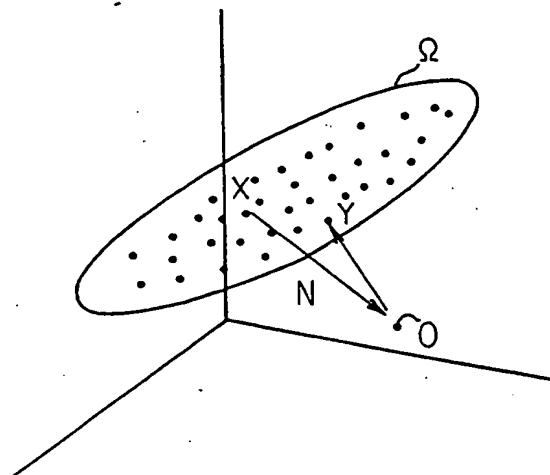


FIG. 9

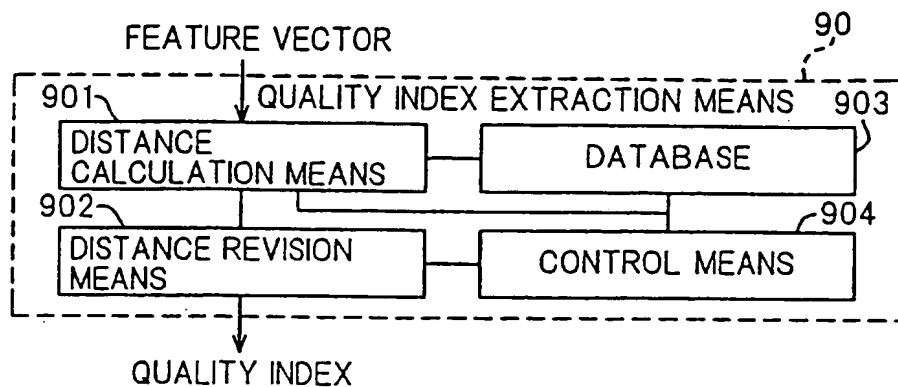


FIG. 10

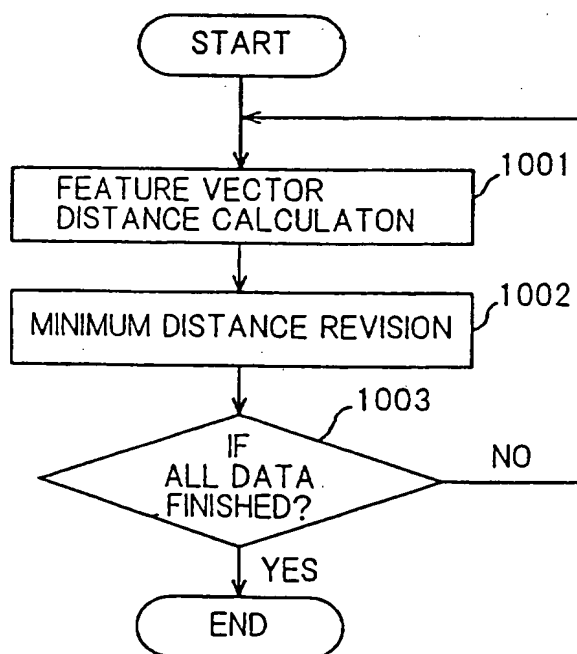


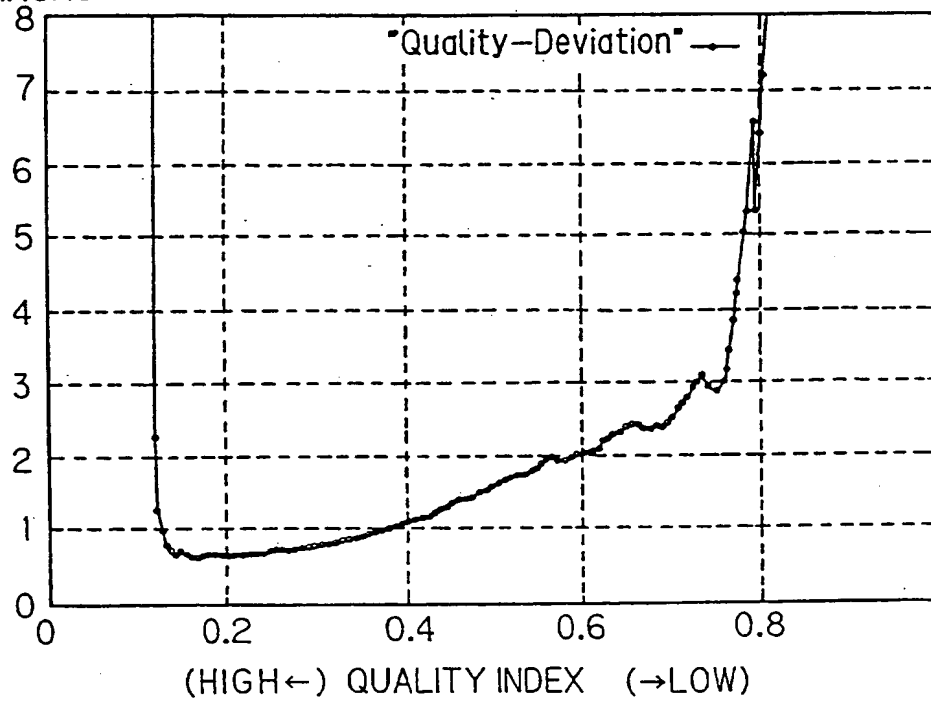
FIG. 11

	$Q < \sigma_1$	$\sigma_2 \leq Q < \sigma_1$	\dots	$\sigma_{n-1} \leq Q$
Q	σ_1	σ_2	\dots	σ_n

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FIG.12

STANDARD DEVIATION
OF ERRORS



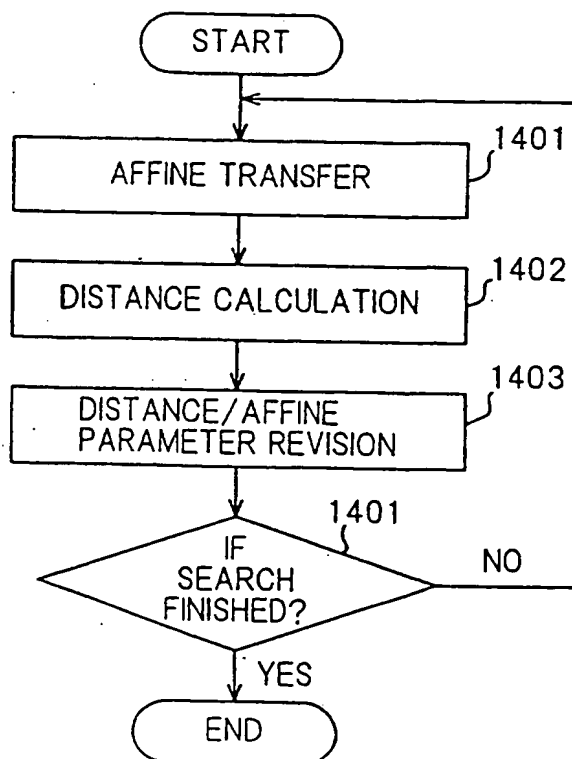


FIG. 15

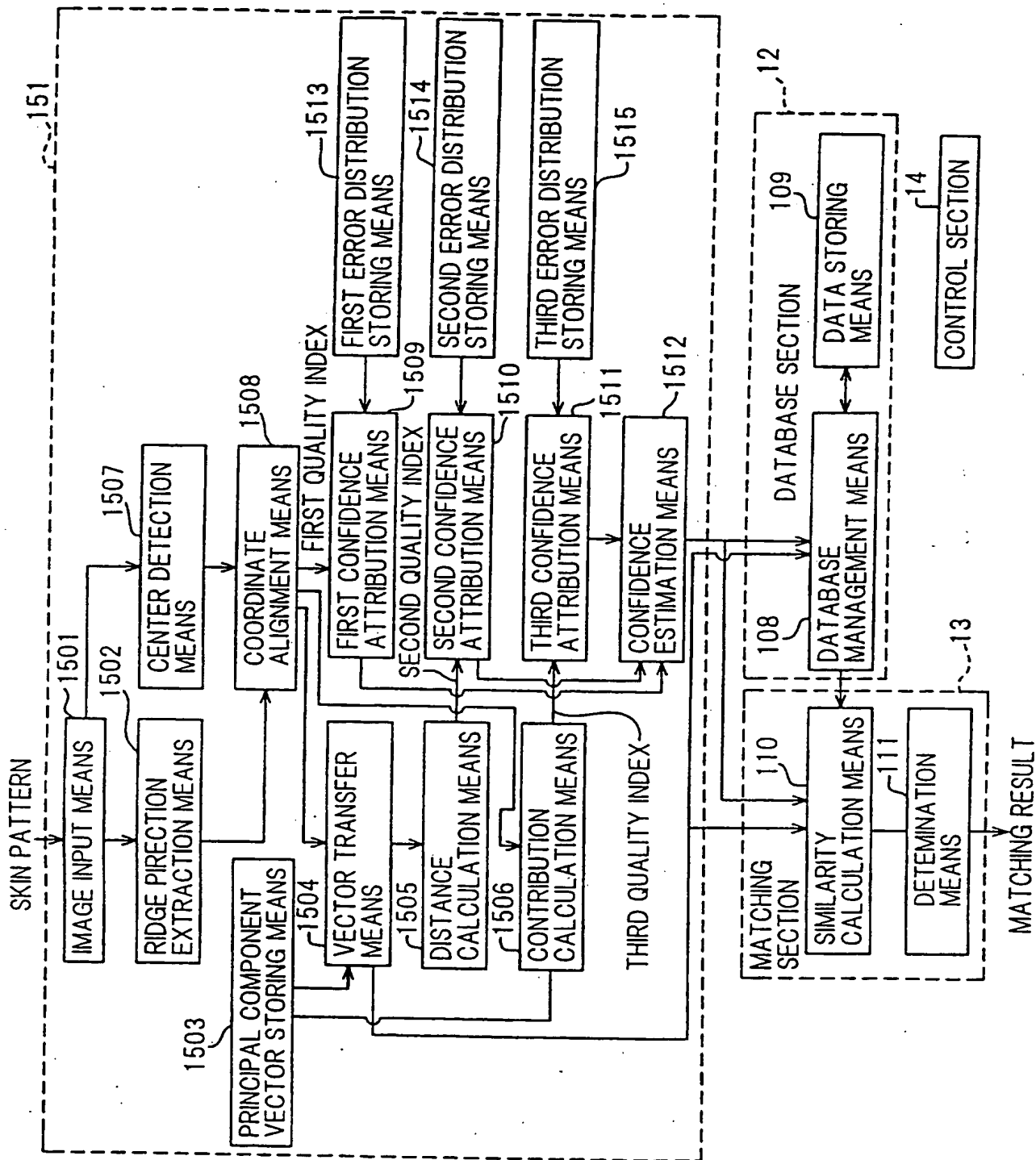


FIG.16

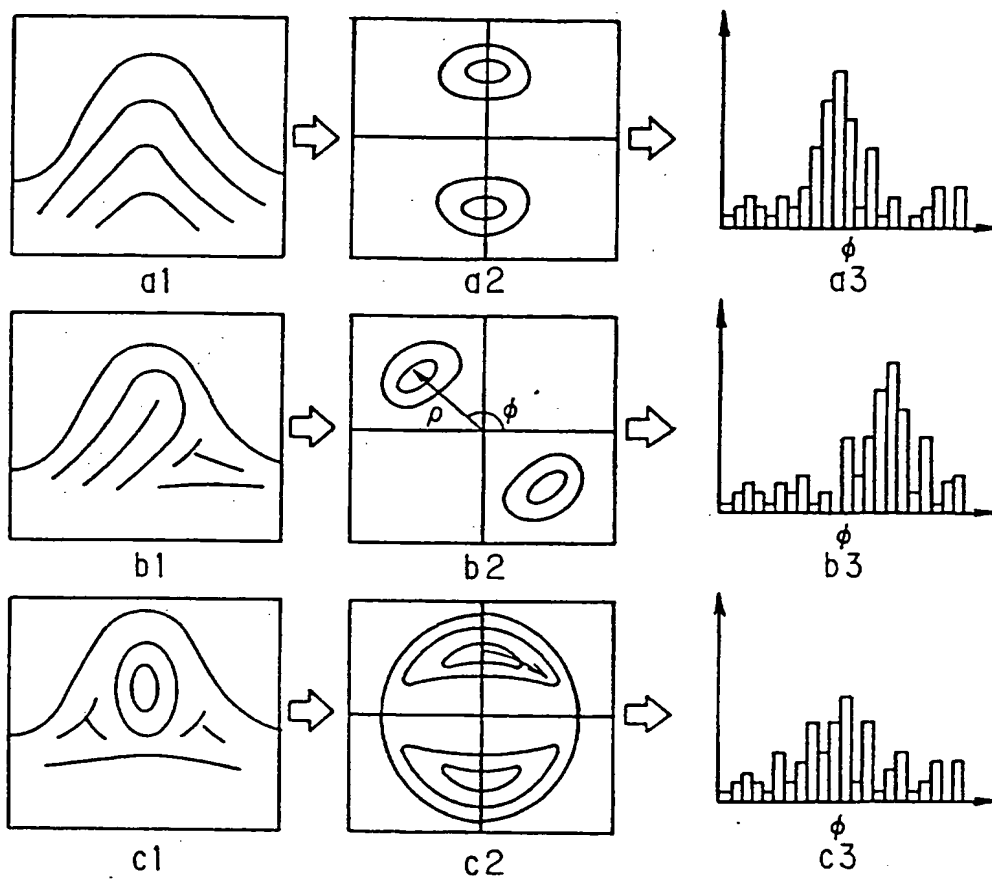


FIG.17

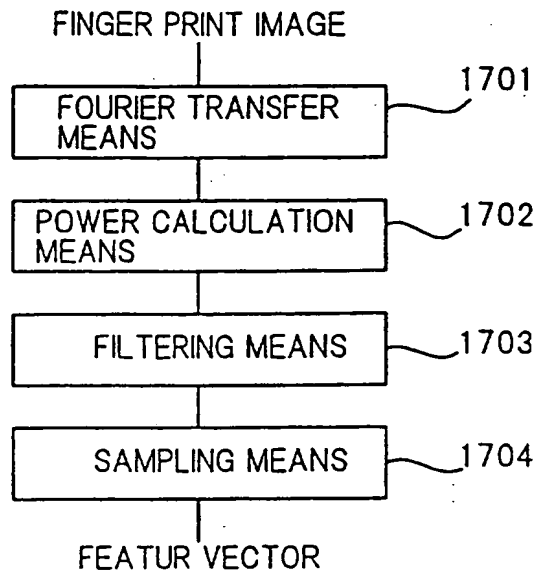


FIG.18

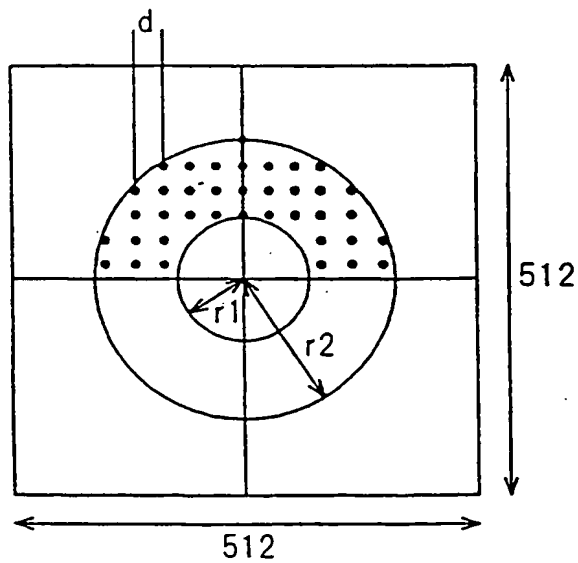


FIG.19

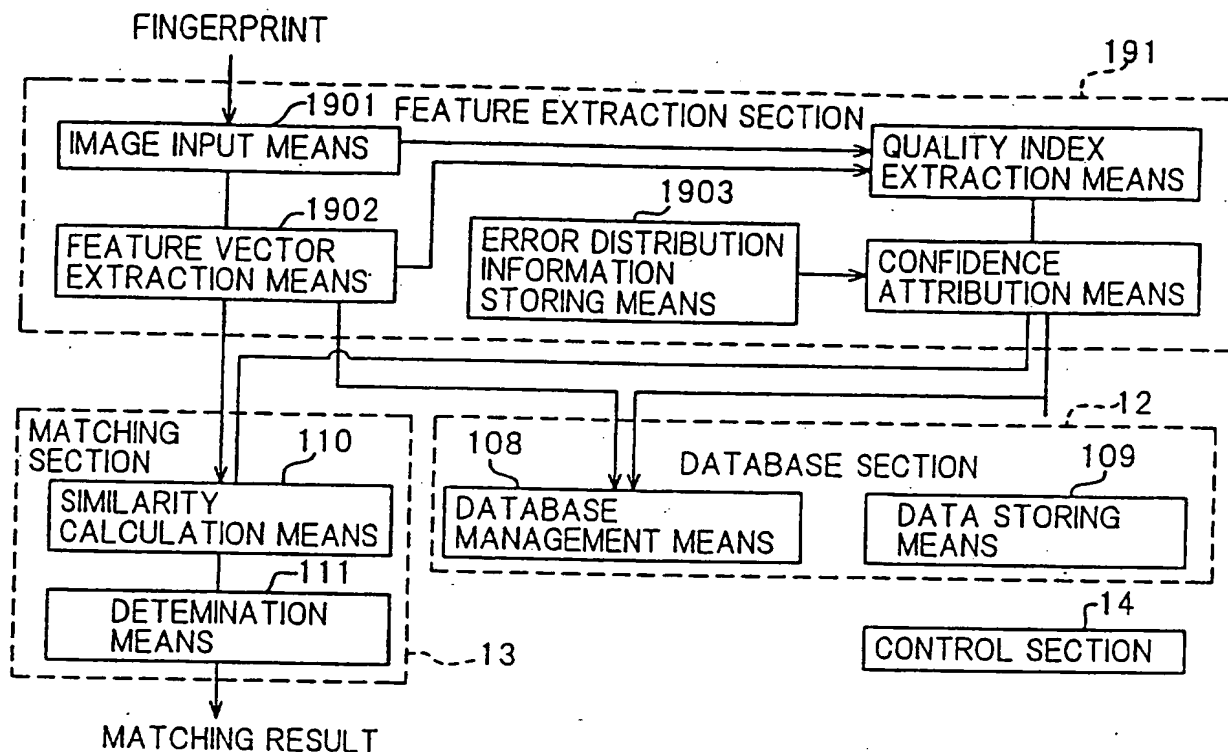
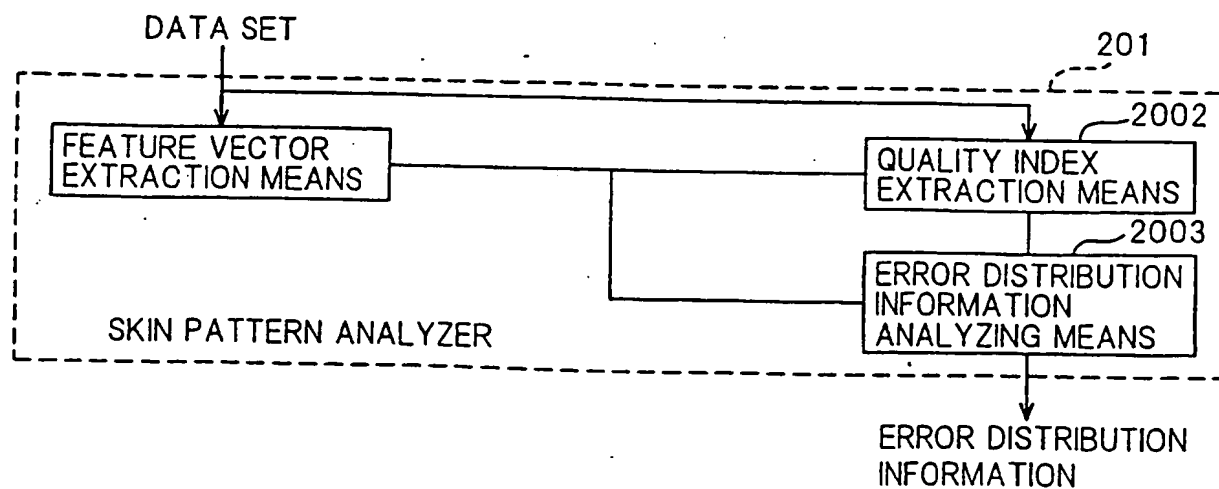


FIG.20



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FIG.21

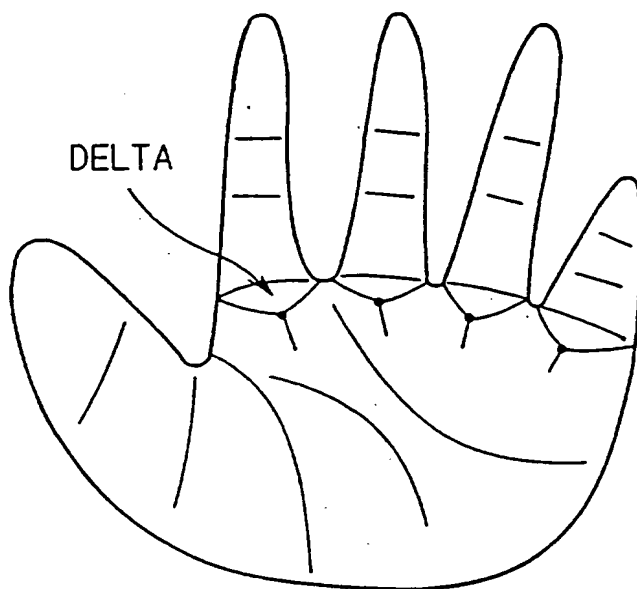


FIG.22

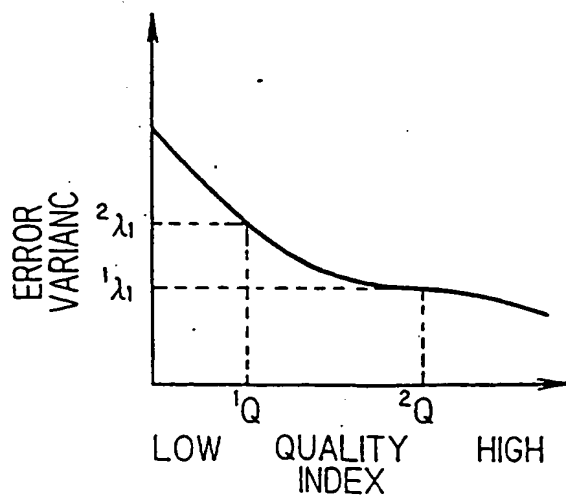


IMAGE COLLATING SYSTEM

The present invention relates to an image collating system, and to an image feature extractor for extracting

5 image features of a pattern image such as a skin pattern image represented by a fingerprint or a palm-print, an image feature analyzer for analyzing the image features, and an image matching system for verifying matching of the pattern image with those filed in a database.

In the following description, the present invention is explained in
10 connection with a skin pattern feature extractor, a skin pattern feature analyzer and a skin pattern matching system applied to personal identification as representative examples of the above devices. However, it will be easily understood that the present invention can be widely applied to matching verification of other pattern images having certain features,
15 and is not limited to the skin pattern matching verification.

As a most orthodox art for identifying a skin pattern such as a fingerprint or a palm-print, there is known a matching verification method making use of feature points of the fingerprint called the minutia matching which is disclosed in a Japanese Patent entitled "Fingerprint Collation System" published as a specification No. 63-34508.
20 However, a disadvantage of the minutia matching is that it takes a lot of computational time because of a large amount of data to be processed.

One method proposed to overcome the aforesaid disadvantage is a technique for reducing
a number of candidates to be verified by way of the Ten Print Card,
25 which is disclosed in "Fingerprint Card Classification for Identification with a Large-Size Database" by Uchida, et al., Technical Report of IEICE (The Institute of Electronics, Information and Communication

Engineers) PRU95-201 (Jan. 1996). In the Fingerprint Classification of this technique, a high-speed rough matching is performed referring to certain features such as the basic fingerprint classification category, distances between singular points, namely, cores or deltas, etc., for pre-selecting candidates to be verified with the minutia matching. As the
5 basic fingerprint classification categories, the fingerprint pattern of each finger is classified into a basic category, such as the Whorl, the Right Loop, the Left Loop or the Arch, and the number of ridge lines and the distances between cores and deltas of each finger
10 are extracted together with their confidence values, and used in the rough matching technique.

The amount of data associated with these features is at most several hundred bytes for a card, far smaller than the several thousand bytes necessary for the minutia matching. The smaller data amount, and consequently the
15 smaller calculation amount enable a high-speed fingerprint verification.

Thus by reducing the number of candidates before the minutia matching is performed, the pre-selection technique of the prior document by Uchida et al. enables the total cost performance of the fingerprint verification system as a whole to be improved.

20 However, because the deltas are usually found in edge parts of the fingerprint, the numbers of ridge lines and the distances between a core and a delta are often difficult to be extracted when a so called roll printing is not performed correctly. The roll printing means here to take the fingerprint pattern by pressing a fingertip rolling on a card, as
25 usually performed when the police take the fingerprint. Furthermore, the above technique is not efficient to pre-select the Arch patterns which have no delta.

Therefore, methods for improving pre-selection performance have been sought. One promising solution is to find other appropriate features to be used for the rough matching in place of or in addition to the above features. One of the possible features is the direction pattern of fingerprint ridge lines. "Personal Verification System with High Tolerance of Poor Quality Fingerprints" by Sasagawa et al., the transactions of IEICE D-II, Vol. J72-D-II, No. 5, pp. 707-714, 1989, is an example of usage of the direction pattern to the rough matching.

Features with many dimensions, such as the direction pattern of the fingerprint ridge lines, makes the high-speed matching verification difficult. Therefore, when evaluating such features,

it is necessary to find a feature extraction method enabling to extract a condensed feature function or value having an appropriate dimension

size giving good results and sufficient efficiency at the same time. A well-known method of such a feature extraction is the principal component analysis. An example of the method applied to the direction pattern of the fingerprint ridge lines is described in a paper of C. L. Wilson et al., entitled "Massively Parallel Neural Network Fingerprint Classification System", NISTIR 4880, 1992, Jul., published by National Institute of Standards and Technology.

In the method of C. L. Wilson et al., the direction pattern is processed as follows.

First, training data of N fingerprint images are prepared. Then, defining feature vectors composed of ridge directions each representing local flow of ridge lines, the principal component analysis is performed for distribution of the feature vectors to obtain principal component vectors having larger eigenvalues. Using the principal component vec-

tors thus obtained, Karhunen Loève Transform (hereafter abbreviated as KLT) of the feature vector of an objective fingerprint image is performed, whereof feature values of upper dimensions are extracted as the condensed feature value.

5 In the following paragraphs, more details of the *feature extraction using the KLT* are described.

For the first, a variance-covariance matrix V is calculated as follows from feature vectors u_i ($i = 1$ to N) of the N fingerprint images prepared for the training.

10
$$V = \frac{1}{N-1} \sum_{i=1}^N (u_i - \bar{u})(u_i - \bar{u})^t \quad (1)$$

$$\bar{u} = \frac{1}{N} \sum_{i=1}^N u_i \quad (2)$$

Here, the feature vectors u_i are column vectors of M dimensions, \bar{u} is a mean vector of u_i , and the upper suffix t means a transpose.

15 Eigenvalues of the variance-covariance matrix V being represented by λ_i ($i = 1, \dots, M; \lambda_i > \lambda_{i+1}$), eigenvectors corresponding to the eigenvalues λ_i are represented by Ψ_i . These eigenvectors Ψ_i are the principal component vectors and one corresponding to a largest eigenvalue λ_1 is called a first principal component vector, followed by a second, a third, ..., a M -th principal component vector in the order
20 of corresponding eigenvalue.

For a feature vector u of an objective fingerprint image, which is not used for the training, projection of the feature vector u to a partial space defined by one or more primary (corresponding to largest eigenvalues) principal component vectors Ψ_i is calculated, that is, projection
25 components v_i around the mean vector \bar{u} are obtained as follows:

$$v_i = \Psi_i^t (u - \bar{u}) \quad (3)$$

The projection components v_i thus obtained are the feature values

extracted by way of the KLT.

In C. L. Wilson et al., a feature vector composed, as its components, of primary projection components u_i corresponding to the primary principal component vectors is input to a neural network for the fingerprint classification. However, these extracted feature values
5 are used only for the classification and any application to the matching verification is not taught therein.

Although it is not applied to the skin pattern analysis, there is described an example of a facial image matching verification making use
10 of feature values obtained by the KLT, in "Eigenfaces for Recognition" by A. Pentland et al., MIT Media Lab Vision and Modeling Group, Technical Report #154 and also in "Probabilistic Visual Learning for Object Detection" by B. Moghaddam and A. Pentland, pp. 786-793 of
15 Proceedings of the 5-th International Conference on Computer Vision, 1995. In these two documents, a method of facial image matching verification is described, wherein a vector consisting of each pixel value of a facial image as each component thereof is used as the source feature vector, and the facial matching verification is performed according to Euclidean distance or Mahalanobis distance of the condensed feature
20 vector extracted by way of the KLM of the source feature vector.

However, these prior arts have their disadvantages when applied to the fingerprint matching verification.

By Uchida et al., it is often difficult to extract sufficient features such as distances or numbers of ridge lines between the core and the
25 delta when the rotation stamping is not performed correctly because the deltas are usually found in edge parts of the fingerprint. Furthermore, the Arch patterns having no delta cannot be pre-selected

sufficiently.

In C. L. Wilson et al., there is a description concerning fingerprint feature extraction making use of the KLT applied to fingerprint classification, but no description concerning application thereof to the fingerprint matching verification is used, for example, to pre-select the verification candidates, as intended in Uchida et al.

Although not to the fingerprint matching verification, application of the KLT to facial image matching verification is disclosed in the documents of A. Pentland et al. The fingerprint image may be processed according to Euclidean distances or Mahalanobis distances in the same way with the above method of A. Pentland et al. However, many of the available fingerprint images are of fairly low grade and sufficient reliability cannot be expected with such a simple method as that of A. Pentland et al., relying simply upon the condensed feature vector. The reason is that necessary consideration is not paid to confidence of the extracted features there.

It is the same with Uchida et al., wherein the distance between pattern images is defined with a feature value and a confidence value. However, the confidence value is calculated heuristically and there is given no logical evidence.

Therefore, a primary object of the present invention is to embody a matching verification architecture for efficiently identifying pattern images such as skin patterns by resolving the above problems, and to provide an image feature extractor, an image feature analyzer and an image matching system, wherein a high-speed and a high-precision processing is realized.

First, the principle of the invention will be explained.

When two feature vectors are given, a variety of distances can be defined between the two feature vectors. As examples thereof, following Euclidean distance, weighted Euclidean distance, Mahalanobis distance, etc., are introduced in pp. 652-658 of "Handbook of Image
5 Analysis" by Takagi et al., Tokyo University Press, 1991.

$$\text{Euclidean distance} \quad D(x, y) = \sqrt{\sum_{i=1}^n (x_i - y_i)^2} \quad (4)$$

$$\text{weighted Euclidean distance} \quad D(x, y) = \sqrt{\sum_{i=1}^n w_i (x_i - y_i)^2} \quad (5)$$

$$\text{Mahalanobis distance} \quad D(x, y) = \sqrt{(x - y)^t V^{-1} (x - y)} \quad (6)$$

10 where, x_i and y_i are respective components of the two feature vectors x and y both having n dimensions, w_i is a corresponding weight factor, and V is a variance-covariance vector of distribution of the feature vectors.

Among them, the Mahalanobis distance is known to give a most
15 natural distance when the feature vectors accord to normal-distribution.

When the two feature vectors x and y are vectors obtained by the KLT, above equation (6) can be represented as follows, which is described also in the documents of A. Pentland et al.

$$20 \quad D(x, y) = \sqrt{\sum_{i=1}^n \frac{(x_i - y_i)^2}{\lambda_i}} \quad (7)$$

where, λ_i are eigenvalues of the variance-covariance vector V . A set of eigenvalues λ_i is defined for a distribution of whole feature vectors or for each of distributions of respective classes of the feature vectors.

As shown by above equation (7), the Mahalanobis distance of the
25 feature vectors obtained by the KLT needs no matrix operation. It can be calculated with a simple square sum operation compatible to equation (5), enabling to reduce computational time.

Suppose, here, to classify the feature vectors into classes $C(Q)$ according to their feature values Q , the feature values Q (hereafter called the quality indexes) being values having correlation with errors of respective feature vectors. To clarify relation between the quality index and the distance used for discriminating a feature vector, different condensed feature vectors, obtained from a specific object image and having their respective quality indexes Q , are considered. Assuming these condensed feature vectors have been processed through the KLT making use of variance-covariance matrix of distribution of source feature vectors, and representing variance among i -th components of the condensed feature vectors classified into each class $C(Q)$ by $\lambda_i C(Q)$, the Mahalanobis distance between two condensed feature vectors x and y belonging to a specific class $C(Q)$ is expressed as follows:

$$D(x, y) = \sqrt{\sum_{i=1}^n \frac{(x_i - y_i)^2}{\lambda_i(C(Q))}} \quad (8)$$

Here, $\lambda_i(C(Q))$ gives an error variance among the feature vectors since it is a variance of distribution of the feature vectors obtained from the same specific object image, provided that the distribution of the feature vectors of the class $C(Q)$ accords to a normal distribution and the eigenvector of the variance-covariance matrix of distribution of the class $C(Q)$ is the same with the eigenvector of the variance-covariance matrix applied to the KLM.

Now, a case is considered wherein the quality index Q and the error variance $\lambda_i(C(Q))$ have a correlation expressing that the better quality index makes the smaller the error variance as illustrated in FIG. 22 (wherein the correlation is represented by that of an i -th dimension), and two different feature vectors x and y , whereof a distance is calculated, have a common quality index.

Representing the common quality index by 1Q of FIG. 22 and corresponding error variance by ${}^1\lambda_i$, a distance $D_1(x, y)$ between the two feature vectors is calculated as follows:

$$D_1(x, y) = \sqrt{\sum_{i=1}^n \frac{(x_i - y_i)^2}{{}^1\lambda_i}}, \quad (9)$$

5 while another distance $D_2(x, y)$ between the same feature vectors x and y is calculated as follows when they have another common quality index 2Q :

$$D_2(x, y) = \sqrt{\sum_{i=1}^n \frac{(x_i - y_i)^2}{{}^2\lambda_i}}. \quad (10)$$

10 Here, it is noted that a relation $D_1(x, y) < D_2(x, y)$ stands when the error variance of each i -th dimension has a relation ${}^1\lambda_i > {}^2\lambda_i$. It means that the Mahalanobis distance varies adaptively to the quality index so as to give a small distance difference estimation when having a poor quality index, that is, giving large error variances ${}^1\lambda_i$, and a large distance difference estimation when having a good quality index
15 to the same two feature vectors x and y , Euclidean distance thereof being constant.

The fact that the distance varies adaptively to the quality index is significant, since thereby incorrect rejection because of data extracted from low grade images can be effectively reduced.

20 In Uchida et al., beforehand described, precision of feature extraction is reflected to a distance value by defining the distance value according to the confidence value (which is heuristically calculated as a value reflecting the feature extraction precision). However, the distance value is defined by a product of the confidence value and a difference
25 between two feature values each belonging to each entirely different dimension, which can be said to be the same thing to define the distance

value by multiplying the height with the weight. Therefore, there is no statistical or theoretical guarantee of precision improvement, even if some good results may be obtained.

On the other hand, by converting the quality index (which can be said to be the confidence) into each error variance among components of respective dimension of the feature vectors as above described, a measure of distances having the same dimensions with the feature vectors can be defined. The Mahalanobis distance is one of the distances which can be defined with statistical support, although there are some restrictions such as the assumption of the normal distribution.

A good discrimination performance can be thus obtained by defining a distance value supported statistically.

Heretofore, a distance between two different feature vectors is described. This is to explain a fact that a strict value of the Mahalanobis distance, which has a statistical significance, can be obtained concerning feature vectors of a specific object, by assuming a normal distribution of the feature vectors. However, the essential merit of the above quality index does not lie in defining the strict Mahalanobis distance itself, but in reflecting correlation between the quality index shown in FIG. 22 and the error distribution of the feature vectors onto the distance definition.

The Mahalanobis distance, which is adaptive to the above quality index, can be obtained by calculating error distributions of different feature vectors in each class obtained from a specific object and sorting them according to their quality index. However, calculation of such values is applicable only to such a special matching verification wherein few objects are treated and only confirmation of identity thereof is

discussed.

For specifying an unknown object, such as intended in the remaining fingerprint verification performed in the criminal investigation, the above distance definition is inapplicable. A distance between feature
5 vectors obtained from different objects should be defined, too.

For the purpose, a distance value which will be described in the following paragraphs can be defined, for example.

A most significant object of the distance definition is to reflect a quality index, or a confidence, to the error distribution. Hence, following three assumptions 1. to 3. are applied to the distance definition.
10

1. The errors included in a feature vector are dependent on its quality index and independent of the feature vector itself.

2. A distribution of the errors included in feature vectors accords to a normal distribution.

15 3. Errors corresponding to a difference between two feature vectors can be estimated from the errors included in each of the two feature vectors.

On the three assumptions, a Mahalanobis-like distance function $\bar{D}(x, y)$ is defined as follows.

20
$$\bar{D}(x, y) = \sqrt{\sum_{i=1}^n \frac{(x_i - y_i)^2}{\bar{\lambda}_i}} \quad (11)$$

$$\bar{\lambda}_i = {}^x\lambda_i + {}^y\lambda_i \quad (12)$$

Here, ${}^x\lambda_i$ and ${}^y\lambda_i$ are variances of the error distributions, depending on the quality index, of components x_i and y_i of the respective feature vectors x and y , and $\bar{\lambda}_i$ represents an estimation of errors corresponding to $x_i - y_i$. The error variances ${}^x\lambda_i$ and ${}^y\lambda_i$ can be prepared
25 through an examination of respective inter-relations such as illustrated in FIG. 22.

Further, the ordinary Mahalanobis distance is said to have a problem that its discrimination performance is degraded in a range where eigenvalues (λ_i) are small because its susceptibility to noises (for example, in "A Handwritten Character Recognition System Using Modified Mahalanobis Distance" by Kato et al., the transactions of IEICE D-II, Vol. J79-D-II, No. 1, pp. 45-52, 1996). Therefore, the distance function may be defined by way of following function.

$$D(x, y) = - \sum_{i=1}^n \log \frac{P(d_i|\alpha)}{P(d_i|\beta)} \quad (13)$$

$$d_i = \frac{x_i - y_i}{\sqrt{\bar{\lambda}_i}} \quad (14)$$

$$\bar{\lambda}_i = {}^x\lambda_i + {}^y\lambda_i \quad (15)$$

Here, α represents a set of differences among feature vectors obtained from a specific pattern, and $P(d_i|\alpha)$ represents a distribution of the differences in the set, namely, the error distribution. On the other hand, β is a set of differences among feature vectors obtained from whole patterns, and $P(d_i|\beta)$ is a distribution of the differences among feature vectors therein.

When the distribution functions $P(d_i|\alpha)$ and $P(d_i|\beta)$ accord to the normal distribution, they are calculated as follows, firstly.

$$P(d_i|\alpha) = \frac{1}{\sqrt{2\pi\lambda_{i,\alpha}}} \exp \left(-\frac{d_i^2}{2\lambda_{i,\alpha}} \right) \quad (16)$$

$$P(d_i|\beta) = \frac{1}{\sqrt{2\pi\lambda_{i,\beta}}} \exp \left(-\frac{d_i^2}{2\lambda_{i,\beta}} \right) \quad (17)$$

where $\lambda_{i,\alpha}$ and $\lambda_{i,\beta}$ are variances of respective distribution functions $P(d_i|\alpha)$ and $P(d_i|\beta)$.

Then, from these distribution functions, the distance function of the equation (13) can be developed as follows.

$$D(x, y) = \frac{1}{2} \sum_{i=1}^n \left(\frac{1}{\lambda_{i,\alpha}} - \frac{1}{\lambda_{i,\beta}} \right) d_i^2 + \sum_{i=1}^n (\log \lambda_{i,\alpha} - \log \lambda_{i,\beta}) \quad (18)$$

$$= \frac{1}{2} \sum_{i=1}^n \left(\frac{1}{\lambda_{i,\alpha}} - \frac{1}{\lambda_{i,\beta}} \right) \frac{(x_i - y_i)^2}{\lambda_i} + \text{const.} \quad (19)$$

Therefore, a Mahalanobis-like distance function such as defined by equation (11) can be composed by obtaining square root of the first term in the right side of equation (19). Difference between the two distance functions is that a weight factor $(\frac{1}{\lambda_{i,\alpha}} - \frac{1}{\lambda_{i,\beta}})$ is attributed to each dimension of the feature vector, in the equation (19). The weight factor is determined according to the error distribution relative to the distribution of the whole patterns. When the error distribution is sufficiently small compared to the whole pattern distribution, the weight factor becomes large, attaching much importance to corresponding dimension. On the contrary, the error distribution is equivalent to the whole pattern distribution, the weight factor becomes small, corresponding dimension being relatively neglected in effect. Thus, an effective result can be obtained with the distance function of equation (19) even from feature vectors including components giving small eigenvalues λ_i , that is, susceptible to noises.

Heretofore, the principle of the invention whereon the embodiments are based is described mainly in connection with feature values obtained through the KLT. This is to clarify statistically and theoretically the effectiveness of the invention, wherein an error distribution is obtained according to the quality index and reflecting the matching verification.

However, application of this invention is not necessarily limited to the feature values processed by the KLT. The most important essence of the invention lies in providing an architecture which enables matching verification

between two image patterns taking in consideration of their confidence, referring to errors of feature values, the errors being adap-

tively measured according to quality index of the image pattern.

In order to embody the matching verification architecture based on the above principle, an image feature extractor of the invention, for outputting a feature information data set of a pattern image including
5 data of a feature vector of the pattern image and confidence estimation information of the feature vector attributed to each component of the feature vector, comprises;

a feature vector extraction means for extracting the feature vector from the pattern image;

10 a quality index extraction means for extracting quality index information of the pattern image;

an error distribution information storing means wherein error distribution information is prepared, the error distribution information representing correlation between error distribution of a plurality of feature
15 vectors extracted by the feature vector extraction means and the quality index information extracted from the quality index extraction means corresponding to the plurality of feature vectors; and

a confidence attribution means for obtaining confidence estimation information referring to the error distribution information prepared in
20 the error distribution information storing means by way of the quality index information extracted from the pattern image by the quality index extraction means.

An image feature analyzer of the invention, for obtaining the error distribution information to be prepared in the error distribution
25 information storing means of the image feature extractor, comprises:

a feature vector extraction means for extracting the plurality of feature vectors from pattern images;

a quality index extraction means for extracting the quality index information from the pattern images; and

a error distribution information analyzing means for calculating the error distribution information from distribution among each feature vector set of the plurality of feature vectors and a value of the quality index information of each feature vector belonging to the each feature vector set, said each feature vector set comprising feature vectors extracted more than one pattern images of a same pattern.

An image feature collating system of the invention for determining the extent of ectypography between pattern images making use of the feature information data set of the pattern image comprises:

a database section wherein the feature information data set of each of a plurality of pattern images is registered; and

a matching section for performing matching verification of the pattern image by discriminating accordance/discordance of the feature information data set registered in the database section according to distance between two feature vectors each included in respective feature information data set calculated in consideration of the confidence information of the two feature vectors.

A system for collating images according to another aspect of the invention comprises means for deriving a feature value for the features of each image; means for deriving a quality index value for the features of each image; means for determining errors for the feature values in which said errors are adaptively measured according to the quality index of the features of each image; and means for determining the extent of ectypography between features of each image.

In a further aspect, the invention provides a method for collating images comprising the steps of determining feature values for image features; deriving quality index values for image features; determining the extent of ectypography between each image by considering the confidence between the features of each image and referring to the errors for the feature values for the two images wherein said errors are adaptively measured according to the quality index of the features of the images.

Therefore, a high-speed and a high-precision method of determining the degree of ectypography between image features can be realized by the image collating system of the invention.

The foregoing, further objects, features, and advantages of this invention will become apparent from a consideration of the accompanying drawings by way of example

In the drawings:

FIG. 1 is a block diagram illustrating a first embodiment of the skin pattern matching system according to the present invention;

5 FIG. 2 is a pattern chart illustrating an example of a set of the ridge directions;

FIG. 3 is a block diagram illustrating a configuration of the quality index extraction means 106 according to the example for obtaining the quality index from the confidence of ridge direction;

10 FIG. 4 is a schematic diagram illustrating data table prepared in the error distribution information storing means 105;

FIG. 5 is a block diagram illustrating a first embodiment of the skin pattern feature analyzer according to the invention;

15 FIG. 6 is a flowchart illustrating processes performed in the skin pattern feature analyzer 51 of FIG. 5;

FIG. 7 is a graphic chart illustrating an analysis result of the skin pattern feature analyzer of FIG. 5;

20 FIG. 8 is a schematic diagram illustrating a feature vector X , originally to be in the closed space Ω when there is no noise, extracted as another feature vector O ;

FIG. 9 is a block diagram illustrating a quality index extraction means 90 according to the second embodiments;

FIG. 10 is a flowchart illustrating processes performed in the quality index extraction means 90 of FIG. 9;

25 FIG. 11 is a schematic diagram illustrating 1-dimensional error distribution table applied to the second embodiments;

FIG. 12 is a graphic chart illustrating an experimental result of

the error distribution table of FIG. 11;

FIG. 13 is a block diagram illustrating a configuration of the quality index extraction means 130 according to the third embodiments;

FIG. 14 is a flowchart illustrating processes performed in the quality index extraction means 130 of FIG. 13;

FIG. 15 is a block diagram illustrating the fourth embodiment of the skin pattern matching system of the invention;

FIG. 16 is a schematic diagram for explaining principle of the fifth embodiment;

FIG. 17 is a block diagram illustrating a feature vector extraction means of the fifth embodiment;

FIG. 18 is a schematic diagram illustrating sampling operation of the sampling means 1704 of FIG. 17;

FIG. 19 is a block diagram illustrating a basic configuration of the sixth embodiment of the skin pattern matching system;

FIG. 20 is a block diagram of a fourth embodiment of the skin pattern feature analyzer of the invention;

FIG. 21 is a schematic diagram illustrating a palm pattern; and

FIG. 22 is a schematic diagram illustrating inter-relation between error variance and quality index.

Now, embodiments of the present invention are described in connection with the drawings. The description will be made in connection with a skin pattern feature extractor, a skin pattern feature analyzer and a skin pattern matching system applied to personal identification as representative examples of the embodiments, namely, an image feature extractor, an image feature analyzer and an image matching system, as previously premised.

In the following paragraphs some embodiments of the skin pattern matching system and the skin pattern feature analyzer are described. As to the skin pattern extractor, it is described as a section, a feature extraction section, of the skin pattern matching system, since the skin pattern feature extractor is to be used as an element of the skin pattern matching system.

FIG. 1 is a block diagram illustration a first embodiment of the skin pattern matching system according to the present invention.

Referring to FIG. 1, the skin pattern matching system of the first embodiment has a feature extraction section 11 for extracting feature data from a skin pattern image, a database section 12 for managing a database storing the feature data extracted by the feature extraction section 11, a matching section 13 for performing matching verification of feature data extracted by the feature extraction 11 of an image to feature data registered in the database section 12, and a control section 14 for controlling each element of the skin pattern matching system. (Here, in the drawings, control lines connecting the control section 14 with each element is not depicted for simplification.) The feature extraction section 11 corresponds to the skin pattern feature extractor to be claimed.

The feature extraction section 11 comprises;

an image input means 101 where image data of a skin pattern such as a fingerprint or a palm print are input,

a feature vector extraction means 102 for extracting a feature vector from image data input through the image input means 101,

a vector transfer means 103 for generating feature information by performing the KLT of the feature vector extracted by the feature

vector extraction means 102,

a principal component vector storing means 104 wherein principle component vectors corresponding to feature values of the feature vectors are prepared to be used for the KLM performed in the vector transfer means 103,

an error distribution information storing means 105 wherein is prepared error distribution information representing correlation between the feature values and quality indexes,

a quality index extraction means 106 for extracting a quality index of the image data input through the image input means 101, and

a confidence attribution means 107 for attributing confidence information to the feature information generated by the vector transfer means 103 according to the quality index extracted by the quality index extraction means 106 referring to the error distribution information prepared in the error distribution information storing means 105.

The feature information generated by the vector transfer means 103 and the confidence information attributed thereto by the confidence attribution means 107 are the feature data extracted of the image data to be output from the feature extraction section 11.

The database section 12 comprises;

a data storing means 109 wherein a plurality of feature data sets extracted by the feature extraction section 11 are registered, and

a database management means 108 taking charge of reference or registration of the plurality of feature data sets in the data storing means 109.

The matching section 13, which performs the skin pattern matching verification for outputting matching results, comprises;

a similarity calculation means 110 for calculating a similarity of the feature data supplied from the feature extraction means 11 to each of the plurality of feature data sets registered in the database section 12, and

5 a determination means 111 for determining accordance/discordance from the similarity calculated by the similarity calculation means 110.

Now, operation of the skin pattern matching system of FIG. 1 is described along with an example wherein the skin pattern matching
10 system is applied to a fingerprint matching verification.

First, procedure in the feature extraction section 11 is described.

The image input means 101 obtains digital 2-dimensional image data of a fingerprint pattern by way of a scanner, a CCD (Charge Coupled Device) camera or the like. It may be configured to obtain
15 the fingerprint image data through a public network from a remote terminal. Here, the fingerprint image data are assumed to be image data having 512×512 binary pixels taken with a resolution of 500 DPI (Dots Per Inch).

The feature vector extraction means 102 extracts a feature vector
20 from the fingerprint image data input through the image input means 101. There can be considered various features to be extracted for the feature vector, beginning with the ridge direction, the ridge line pitch and so on. In this example, focusing on the ridge direction feature, the feature vector is described to be extracted making use of an "Apparatus
25 for determining ridge line direction patterns" disclosed in a Japanese patent application laid open as a Provisional Publication No. 7097/'96.

Here, the fingerprint image data input by the image input means

101 are represented as $f(x, y)$, x and y being horizontal and vertical coordinates thereof having integer values from 1 to 512. With the apparatus of the Provisional Publication No. 7097/'96, a ridge direction $\theta(C)$ having a value $0 \leq \theta(C) < \pi$ can be extracted for each sub-region C defined in the image data $f(x, y)$. In an example, 256 sub-regions C ($C = 1, 2, \dots, 256$) are defined horizontally and vertically at every 32 pixels in a set of image data of 512×512 pixels.

FIG. 2 is a pattern chart illustrating an example of a set of the ridge directions thus extracted, wherein the ridge direction and its confidence of each sub-region are represented by direction and length of each corresponding segment, respectively. When the ridge direction is expressed by such an angle value from 0 to π as in the Provisional Publication No. 7097/'95, a discontinuity arises between $\theta = \pi$ and $\theta = 0$, which is inconvenient for the feature vector. Therefore, the ridge direction $\theta(C)$ is converted into vector components $u_x(C)$ and $u_y(C)$ according to following equations.

$$u_x(C) = \cos(2\theta(C)) \quad (20)$$

$$u_y(C) = \sin(2\theta(C)) \quad (21)$$

Thus, a following feature vector u having 512 dimensions consisting of the vector components $u_x(C)$ and $u_y(C)$ of every sub-region C is output from the feature vector extraction means 102 of FIG. 1.

$$\mathbf{u} = \begin{pmatrix} u_x(1) \\ u_x(2) \\ \vdots \\ u_x(256) \\ u_y(1) \\ u_y(2) \\ \vdots \\ u_y(256) \end{pmatrix} \quad (22)$$

The vector transfer means 103 performs the KLM of the feature vector \mathbf{u} extracted by the feature vector extraction means 102 according to principal component vectors prepared in the principal component vector storing means 104. As for the principal component vectors, outputs of a first embodiment (which will be described afterwards) of the skin pattern feature analyzer may be prepared in the principal component vector storing means 104, for example. Here, consider there are prepared L principal component vectors Ψ_i ($i = 1, 2, \dots, L$). Each of the principal component vectors Ψ_i has the same dimensions with the feature vectors \mathbf{u} and expressed as a column vector.

The vector transfer means 103 calculates the KLT of the feature vector \mathbf{u} for each i -th of the L principal component vectors Ψ_i according to following equation from the feature vector \mathbf{u} and the principal component vector Ψ_i .

$$v_i = \Psi_i^t \mathbf{u} \quad (23)$$

Thus, a following condensed feature vector \mathbf{v} is obtained from the source feature vector \mathbf{u} through the KLT.

$$\mathbf{v} = \begin{pmatrix} v_1 \\ v_2 \\ \vdots \\ v_L \end{pmatrix} \quad (24)$$

As will be described in connection to the first embodiment of the skin pattern feature analyzer, sufficient precision can be attained with a small number (five, for example) of principal component vectors, which defines the dimension number L of the condensed feature vector. The condensed feature vectors of five dimensions enables to reduce data amount into about 1/100 of the source feature vector having 512 dimensions of ridge direction features.

In case where a mean vector $\bar{\mathbf{u}}$ is already prepared by calculating mean value of the plurality of sample feature vectors \mathbf{u} , the previous described equation (3) may be applied instead of above equation (23) for performing the KLT of the source feature vector \mathbf{u} .

The quality index extraction means 106 extracts the quality index through following procedure.

The quality index may be represented by any data, provided that the data have correlation with errors included in the feature vector \mathbf{u} . Here, calculation of the quality index making use of the confidence value discussed also in the prior apparatus of the Provisional Publication No. 7097/'96 is described by way of example, which is obtained along with determining the ridge direction.

FIG. 3 is a block diagram illustrating a configuration of the quality index extraction means 106 according to the example for obtaining the quality index from the confidence of ridge direction.

The quality index extraction means 106 comprises a ridge direc-

tion confidence extraction means 301 for extracting the ridge direction confidence from input image data 31, a second principal component vector storing means 302 for storing principal component vectors, and a data conversion means 303 for generating quality index data 32 from the ridge direction confidence extracted by the ridge direction confidence extraction means 301 and the principal component vectors stored in the principal component vector storing means 302.

The ridge direction confidence extraction means 301 calculates a confidence value $q(C)$ of ridge direction $\theta(C)$ of each sub-region, making use of eigenvalues of variance-covariance matrix of a gradient vector of concerning sub-region C in the same way as disclosed in the Provisional Publication No. 7079/'96. As beforehand premised, the quality index may be calculated in another way, and complicated description is omitted, here. Furthermore, the prior apparatus of the Provisional Publication No. 7079/'96 outputs the confidence value $q(C)$ together with the ridge direction $Q(C)$. Therefore, the feature vector extraction means 102 of FIG. 1 may be included in the ridge direction confidence extraction means 301.

In the second principal component vector storing means 302, the same L principal component vectors with those stored in the principal component vector storing means 104 are prepared. Hence, the principal component vector storing means 104 in the feature extraction section 11 may be commonly referred to by the data conversion means 303 instead of the second principal component vector storing means 302.

The data conversion means 303 calculates quality index values Q_i from the confidence value $q(C)$ and the principal component vectors Ψ_i according to following equation.

$$Q_i = \sqrt{\sum_C \eta(C)^2 \Psi_i(C)^2} \quad (25)$$

Here, $\Psi_i(C)$ represents C -th component of i -th principal component vector Ψ_i .

Thus, L quality index values Q_i corresponding to L principal component vectors Ψ_i are calculated for a set of image data 31. As the quality index data 32, the data conversion means 106 outputs a following quality vector Q consisting of the L quality index values Q_i as its components.

$$Q = \begin{pmatrix} Q_1 \\ Q_2 \\ \vdots \\ Q_L \end{pmatrix} \quad (26)$$

In the error distribution information storing means 105, error distribution information, which is also calculated by the first embodiment, for example, of the skin pattern feature analyzer to be described afterwards, is prepared. In the first embodiment, a standard deviation $\sigma(v_i; Q_i)$ of each component v_i of a condensed feature vector v is calculated when a corresponding component Q_i of the quality vector Q , corresponding to the condensed feature vector v , is given.

FIG. 4 is a schematic diagram illustrating data table prepared in the error distribution information storing means 105.

Referring to the data table in the error distribution information storing means 105, the confidence attribution means 107 outputs a following confidence vector σ by calculating a standard deviation value corresponding to the quality vector Q supplied from the quality index extraction means 106. For example, when a first component Q_1 of the quality vector Q has a value in a range $\alpha_1 \leq Q_1 < \alpha_2$, the data table of FIG. 4 is retrieved and a standard deviation value $\sigma_{1,2}$ is output.

In the same way, a certain standard deviation value, denoted by σ_i , is output for every quality component Q_i . Thus, a following confidence vector σ is obtained from the confidence attribution means 107.

$$\sigma = \begin{pmatrix} \sigma_1 \\ \sigma_2 \\ \vdots \\ \sigma_L \end{pmatrix} \quad (27)$$

Secondly, procedure performed in the database section 12 is described.

The database section 12 takes charge of data recording controlled by the control section 14 or data reading to be delivered to the matching section 13 upon referring request.

Controlled by the control section 14, the database management means 108 registers the feature vector v and corresponding confidence vector σ in the data storing means 109 together with data management information thereof such as data ID (IDentification).

As for the data storing means 109, a semiconductor memory such as a DRAM (Dynamic Random Access Memory) and data recording media such as a hard disk device are used.

In conventional fingerprint matching systems, it has been hardly possible to prepare all the necessary data in a DRAM in economical view, because of their enormous data amount. (According to a method described in "Automated Fingerprint Identification by Minutia-Network Feature - Matching Processes -" by Asai et al., the transactions of IEICE D-II, Vol. J72-D-II, No. 5, pp. 733-740, 1989, for example, data for one finger amount up to 1000 bytes.) Further, even if the necessary data may be deployed in a DRAM for high-speed processing, data transfer of large amount of data would have become

another bottleneck in most case.

However, according to the skin pattern matching system of the embodiment, or the present invention, the condensed feature vector v and the confidence vector σ do not amount but only to 10 bytes par
5 finger even when five dimensions of one byte are considered for each vector. Therefore, a data storage of 100M bytes becomes sufficient for storing data of 10 million (10^7) fingerprints, enabling to deploy all the necessary data in a high-speed accessible semiconductor memory, a DRAM, in the data storing means 109. The hard disk is used here
10 in parallel to backup the DRAM against incidents. A semiconductor disk, namely, a nonvolatile memory such as a flash memory, may be applied instead of the combination of the DRAM and the hard disk device.

When registered data are referred to, the database management
15 means 108 sends each pair of the condensed feature vector v and the confidence vector σ to the matching section 13.

Now thirdly, procedure in the matching section 13 is described.

Controlled by the control section 14, the matching section 13 determines accordance/discordance of the data sent from the feature extraction section 11 to each data set delivered from the database section
20 12, and outputs data management information such as the data ID of data sets regarded to have accordance with the data sent from the feature extraction means 11, as follows.

The similarity calculation means 110 calculates a similarity of a
25 pair of the feature vector and the confidence vector sent from the feature extraction means 11 to those delivered from the database section 12. In the following paragraphs, the feature vector and the confidence

vector from the feature extraction section are denoted as v^s and σ^s , respectively, while those from the database section are denoted as v^f and σ^f , respectively. The similarity $z(v^s, v^f, \sigma^s, \sigma^f)$ is calculated according to following equation.

$$5 \quad z(v^s, v^f, \sigma^s, \sigma^f) = \sum_{i=1}^L \left(\frac{1}{\sigma_{i,\alpha}^2} - \frac{1}{\sigma_{i,\beta}^2} \right) \frac{(v_i^s - v_i^f)^2}{\sigma_i^f \sigma_i^s} \quad (28)$$

Here, v_i^s and v_i^f represent respective components of the feature vectors v^s and v^f and σ_i^s and σ_i^f represent respective component of the confidence vector σ^s and σ^f .

The similarity $z(v^s, v^f, \sigma^s, \sigma^f)$ is a scale of likeness and the smaller the similarity, the better the two feature vectors resemble.

The similarity calculation means 110 may calculate the similarity as follows instead of above equation.

$$z(v^s, v^f, \sigma^s, \sigma^f) = \sum_{i=1}^L \left(\frac{1}{\sigma_{i,\alpha}} - \frac{1}{\sigma_{i,\beta}} \right) \frac{|v_i^s - v_i^f|}{\sqrt{\sigma_i^f \sigma_i^s}} \quad (29)$$

When calculating the similarity according to equation (29), computational time can be reduced by beforehand preparing inverse square root, $1/\sigma^{1/2}$, of each element of both the matching confidence vector σ (from the feature extraction section) and the reference confidence vector σ (from the database section 12). Equation (29) defines a distance when the error distribution function accords to Laplace distribution (according to a distribution function $f(x) = k \exp(-a|x|)$). The dual-exponential distribution is sometimes applied for estimating errors including certain amount of singular noises, and the equation (29) gives better discrimination results than the equation (28) when low grade images are treated.

Returning to the above equations, $\sigma_{i,\alpha}$ and $\sigma_{i,\beta}$ are both parameters whereof values are predetermined. For determining the parameter values, following example is an easy way to calculate them.

That is, preparing K (10 thousands, for example,) pairs of different fingerprint images, each pair taken from each of K different fingerprints, the feature vector v and the confidence vector σ of each image are calculated by the feature extraction section 11. Denoting
 5 respective vectors of a j -th pair by $v^{f,j}$, $\sigma^{f,j}$ and $v^{s,j}$, $\sigma^{s,j}$ ($j = 1, 2, \dots, K$), the parameters $\sigma_{i,\alpha}$ and $\sigma_{i,\beta}$ are calculated as follows.

$$d_i^{j,k} = \frac{|v_i^{f,j} - v_i^{s,k}|}{\sigma_i^{f,j} \sigma_i^{s,k}} \quad (30)$$

$$\sigma_{i,\alpha} = \sqrt{\frac{1}{K-1} \sum_{j=1}^K \left(d_i^{j,j} - \sum_{k=1}^K d_i^{k,k} \right)^2} \quad (31)$$

$$\sigma_{i,\beta} = \sqrt{\frac{1}{K-1} \sum_{j=1}^K \sum_{k=1}^K \left(d_i^{j,k} - \sum_{l=1}^K \sum_{m=1}^K d_i^{l,m} \right)^2} \quad (32)$$

The determination means 111 selects and outputs information of the data which can be regarded to be coincide with the data supplied from the feature extraction means 11 among those registered in the
 15 database section 12.

In the accumulation calculation performed according to the equation (28) or (29) by the similarity calculation means 110, the calculation may be finished determining there is no coincidence when the distance accumulation attains to a certain threshold value.

20 Thus, a fingerprint matching verification is performed in the skin pattern matching system of the embodiment.

Now, the skin pattern feature analyzer is described.

FIG. 5 is a block diagram illustrating a first embodiment of the skin pattern feature analyzer according to the invention.

25 The skin pattern feature analyzer is used for analyzing distribution information among feature vectors extracted from a data set of skin pattern images, and outputs principal component vectors of the

feature vector distribution and error distribution information representing error correlation between the quality indexes and the feature vectors.

Referring to FIG. 5, the skin pattern feature analyzer 51 of the first embodiment comprises;

a feature vector extraction means 501 for extracting a feature vector from a skin pattern image,

a principal component vector calculation means 502 for calculating principal component vectors of data distribution of the skin pattern images represented by the feature vectors extracted by the feature vector extraction means 510,

a principal component vector storing means 503 for storing principal component vectors obtained by the principal component vector extraction means 502,

a vector transfer means 504 for obtaining condensed feature vectors by performing the KLT of feature vectors extracted by the feature vector extraction means 501,

a quality index extraction means 505 for extracting a quality index of the skin pattern images, and

an error distribution information analyzing means 506 for analyzing correlation between error distribution of the quality index information delivered from the quality index extraction means 505 and that of the condensed feature vectors transferred by the vector transfer means 505.

FIG. 6 is a flowchart illustrating processes performed in the skin pattern feature analyzer 51 of FIG. 5, comprising a training feature vector extraction step 601, a variance-covariance matrix data accu-

mulation step 602, a data finish determination step 603, an average vector/variance-covariance matrix calculation step 604, principal component vector calculation step 605, a quality index calculation step 606, a pair vector extraction step 607, a pair vector KLT step 608, a pair vector error calculation step 609, an error distribution statistics calculation step 610, a pair vector finish determination step 611, and an error distribution output step 612.

Now, operation of the embodiment is described, along with processes performed for preparing the principal component vectors to be used in the principal component vector storing means 104 and the error distribution information to be used in the error distribution information storing means 105 of FIG. 1, by way of example.

A data set of skin pattern images should be beforehand prepared for obtaining the principal component vectors and the error distribution information to be used for the skin pattern matching system of the invention. Here also, a data set of fingerprint images are described to be prepared, by way of example, for obtaining above data concerning fingerprints to be used for the skin pattern matching system of FIG. 1.

The data set is assumed to comprise data of N pairs (total $2N$) of different images of N fingerprints. The better, the more number of pairs are applied for obtaining the error distribution information, but pairs more than 10 thousands give comparatively good results. The data set may be gathered by way of an image input device such as an image scanner as mentioned in connection with the first embodiment of the skin pattern matching system. However, a fingerprint database published by US National Institute of Standards and Technology (hereafter abbreviated as NIST), the NIST Special Database

14, for example, is available. For cutting out image data of 512×512 pixels from those of the NIST database, image center thereof should be detected, whereof a method is disclosed in a Japanese patent published as a specification No. 271884/89, for example.

5 Returning to FIG. 6, extraction of the principal component vectors (steps 601 to 605) is described firstly.

At steps 601 to 606, $2N$ feature vectors are extracted from the data set of $2N$ fingerprint images, a variance-covariance matrix of distribution of the $2N$ feature vectors is calculated, and the principal
10 component vectors are obtained from the variance-covariance matrix.

As for obtaining the principal component vectors themselves, it is not necessary to prepare data set of paired fingerprint images. However, it is economical to use the same data set for obtaining both the principal component vectors and the error distribution information.
15 Therefore, the principal-component vector calculation is described to be performed with the $2N$ fingerprint images, in the following paragraphs.

The feature vector extraction means 501 extracts M (512 in the example) dimensional feature vectors u_i ($i = 1, 2, \dots, 2N$), each represented by equation (22), from the data set of $2N$ fingerprint images
20 (at step 601), in the same way as the feature vector extraction means 102 of FIG. 1.

The principal component vector extraction means 503 calculates statistic data of the extracted feature vectors u_i for obtaining a
25 variance-covariance matrix V thereof represented by equation (1).

For calculating the variance-covariance matrix V directly according to equation (1), an average vector \bar{u} should be calculated first

by accumulating each of $2N$ of u_i , and then the variance-covariance matrix V should be calculated by referring to each u_i according to equation (1). Therefore, all $2N$ of u_i must be retained in a memory, or the feature vectors u_i should be extracted twice for each operation.

5 By this reason, the principal component vector calculation means 502 of the embodiment calculates the variance-covariance matrix V according to following equation (34).

$$V = \frac{1}{2N-1} \sum_{i=1}^{2N} (u_i - \bar{u})(u_i - \bar{u})^t \quad (33)$$

$$= \frac{1}{2N-1} \sum_{i=1}^{2N} u_i u_i^t - \bar{u} \bar{u}^t \quad (34)$$

$$\bar{u} = \frac{1}{2N} \sum_{i=1}^{2N} u_i \quad (35)$$

That is, an accumulation of the M dimensional feature vectors u_i for obtaining the mean vector \bar{u} , and another accumulation of $M \times M$ matrix $u_i u_i^t$ for obtaining first term $\frac{1}{2N-1} \sum_{i=1}^{2N} u_i u_i^t$ of left side of the
15 above equation (34) are sufficient to be calculated at step 602. These accumulations can be accomplished each time when an individual feature vector u_i is extracted. Therefore, it is not necessary to retain all the feature vectors u_i at the same time or to extract them twice.

After the steps 601 and 602 are repeated for the data set of every of the fingerprint images (determined at step 603), the principal
20 component vector calculation means 502 calculates (at step 604) second term of left side of the equation (34) from the mean vector \bar{u} thus accumulated, for obtaining the variance-covariance matrix V .

Then, (at step 605) the principal component vector calculation
25 means 502 calculates the principal component vectors by way of principal component analysis of distribution of the feature vectors u_i with its variance-covariance matrix V obtained at step 604. The principal

component analysis is well known and briefly described in the previous paper of G. L. Wilson et al. An explanation thereof can be also found in pp. 40-42 of the "Handbook of Image Analysis" previously referred to.

5 M principal component vectors Ψ_i ($i = 1, 2, \dots, M$; called a first, a second, ..., an M -th principal component vector, in order of sizes of corresponding eigenvalues) are obtained from a variance-covariance matrix V of $M \times M$ dimensions. Upper several principal component vectors among them are sufficient to be used for the KLM. An appropriate employment number may be determined experimentally by
10 performing the matching verification experimentally using feature vectors actually processed through the KLM. In the case of the fingerprint image, upper two principal component vectors have conspicuously good characteristic. Hence, upper 5 to 6 principal component vectors corresponding to largest eigenvalues are sufficient to be applied. Here, L
15 principal component vectors are assumed to be selected.

Returning to FIGs. 5 and 6, the principal component vector calculation means 502 stores the L principal component vectors Ψ_l ($l = 1, 2, \dots, L$) in the principal component vector storing means 503.

20 Thus, extraction of the L principal component vectors Ψ_l is performed.

Then, the error distribution analysis is described referring to steps 606 to 612 of FIG. 6.

In the error distribution analysis, correlation between the error
25 distribution and the quality index of paired condensed feature vectors, obtained from a data set of paired images and processed through the KLT, is calculated. As beforehand premised, the error distribution

analysis will be described to use the same data set of N pairs of fingerprint images used to obtain the principal component vectors Ψ_l . However, it may be performed with another data set of sufficient number of paired and different fingerprint images, each pair thereof taken from a same finger.

At steps 606 to 611, error distribution information is obtained from the quality indexes and the condensed feature vectors of the paired fingerprint image data.

The quality index extraction means 505 calculates (at step 606) a quality vector $Q_{i,j}$ ($i = 1, 2, \dots, N; j = 1, 2$) of each ($j = 1, 2$) of i -th pair of images in the same way as described in connection with the skin pattern matching system of FIG. 1, according to following equations.

$$Q_{i,j} = \begin{pmatrix} Q_{i,j,1} \\ Q_{i,j,2} \\ \dots \\ Q_{i,j,l} \\ \dots \\ Q_{i,j,L} \end{pmatrix} \quad (36)$$

$$Q_{i,j,l} = \sqrt{\sum_C q_{i,j,l}(C)^2 \Psi_l(C)^2} \quad (37)$$

Here, $q_{i,j,l}(C)$ and $\Psi_l(C)$ ($l = 1, 2, \dots, L$) are C -th components of the ridge direction confidence vector and that of the principal component vector to be used for the KLT, respectively, as described in connection with equation (25). The quality vectors $Q_{i,j}$ thus calculated are supplied to the error distribution information analyzing means 506.

On the other hand, the feature vector extraction means 501 extracts (at step 607) feature vectors $u_{i,j}$ ($i = 1, 2, \dots, N; j = 1, 2$) from image data of i -th fingerprint.

The vector transfer means 504 performs the KLT of the paired

feature vector $u_{i,j}$ (at step 608), that is, performs the KLT according to following equation (38) making use of L principal component vectors Ψ_l to obtain paired condensed feature vectors $v_{i,j}$.

$$v_{i,j,l} = \Psi_l^t u_{i,j} \quad (38)$$

$$v_{i,j} = \begin{pmatrix} v_{i,j,1} \\ v_{i,j,2} \\ \dots \\ v_{i,j,l} \\ \dots \\ v_{i,j,L} \end{pmatrix} \quad (39)$$

The paired condensed feature vectors $v_{i,j}$ thus obtained are also supplied to the error distribution information analyzing means 506.

The error distribution information analyzing means 506 analyzes correlation between the quality index and the error distribution referring to quality vectors $Q_{i,j}$ delivered from the quality index extraction means 505 and the condensed feature vectors $v_{i,j}$ delivered from the vector transfer means 504, and prepares a lookup table, or an error distribution table, representing relation between standard deviation of error values to quality index such as illustrated in FIG. 4 concerning each dimension of these vectors having the same L dimensions. More concretely, each time when a pair of condensed feature vectors $v_{i,j}$ and corresponding pair of quality vectors $Q_{i,j}$ are delivered, the error distribution information analyzing means 506 registers error value of each component of the condensed feature vectors into a corresponding table entry prepared for each dimension according to ranks k of the quantized quality index value (at step 609), for calculating standard deviation $\sigma_{k,l}$ of the error values for each rank k of each dimension l according to following equations, said error value being deviation of

each of components of the condensed feature vectors $V_{i,j}$ from their mean value.

$$\sigma_{k,l} = \sqrt{\frac{1}{N_{k,l} - 1} \sum_{Q_{i,j,l} \in k} (v_{i,j,l} - \bar{v}_{i,l})^2} \quad (40)$$

where $N_{k,l} = \sum_{Q_{i,j,l} \in k} 1$, $\bar{v}_{i,l} = \frac{1}{\sum_j 1} \sum_j v_{i,j,l}$, and

$$\sigma_{k,l} = \sqrt{\frac{1}{4(N_{k,l} - 1)} \sum_{Q_{i,j,l} \in k} (v_{i,1,l} - v_{i,2,l})^2} \quad \text{when } j = 1, 2. \quad (41)$$

Here, $N_{k,l}$ is a number of data classified into each table entry, and first summation $\sum_{Q_{i,j,l} \in k}$ means a summation of concerning data corresponding to quality index value $Q_{i,j,l}$ to be quantized into k -th rank. The error value as above defined in equation (40) becomes difference between corresponding components of each pair of the condensed feature vectors obtained from the same fingerprint, when the data set is composed of paired (only two) image data. When more than two images from one fingerprint can be obtained, more precise mean value estimation, and hence, error value estimation can be obtained. Therefore, the more images are the more preferable.

In the embodiment of FIG. 5, the error distribution information analyzing means 506 operates as follows.

In advance, threshold values for quantizing each component of the quality vectors $Q_{i,j}$ are determined according to distribution of the quality vectors $Q_{i,j}$. When value range of a dimension of the quality vector $Q_{i,j}$ is from Q_{min} to Q_{max} , each of the threshold values $\alpha_1, \alpha_2, \dots, \alpha_{n-1}$ is determined so as to quantize the value range into n ranks, 256, for example. Corresponding to each rank of each dimension, an error distribution table having $n \times L$ entries is prepared.

The error distribution information analyzing means 506 compares (at step 610) each component $Q_{i,1,l}$ of a quality vector $Q_{i,1}$ to the

threshold values α_i for obtaining corresponding rank $k_{1,l}$, and accumulates a square error value $(v_{i,1,l} - v_{i,2,l})^2$ of equation (41) calculating from corresponding components of corresponding pair of condensed feature vectors $v_{i,1}$ and $v_{i,2}$ onto a table entry indicated by the rank $k_{1,l}$. The same square error value $(v_{i,1,l} - v_{i,2,l})^2$ is also accumulated onto another (or the same) table entry indicated by another rank $k_{2,l}$ obtained from partner quality vector $Q_{i,2}$. Thus, square error values of all dimensions of the pair of feature vectors $v_{i,1}$ and $v_{i,2}$ are registered in the error distribution table.

After finishing registration of the square error values of all pairs of feature vectors in the data set (determined at step 611), the error distribution information analyzing means 506 outputs the standard deviation $\sigma_{k,l}$ of the error values of each table entry calculated according to equation (41) as the error distribution information (at step 612). When there is no data or only one square error value in a table entry, the equation (41) cannot be applied. In the case, a certain default value may be output, or a value interpolated from neighboring table entry may preferably output, when the quality index is quantized sufficiently fine, into 256, for example.

Thus, the principal component vectors and the error distribution information previously described to be referred to by the first embodiment of FIG. 1 of the skin pattern matching system are analyzed.

FIG. 7 is a graphic chart illustrating an analysis result, that is, an experimental output representing standard deviation of errors of a dimension according to quality index value.

In the foregoing paragraphs, first embodiments of the skin pattern matching system and the skin pattern feature analyzer are described,

wherein eigenvalues obtained along with ridge direction extraction are used as the quality index.

In the following paragraphs, second embodiments of the skin pattern matching system and the skin pattern feature analyzer are described, wherein the quality index is calculated according to a distance of a concerning feature vector from a proper distribution of feature vectors.

First, principle of quality index measurement of the second embodiments is described.

10 In the second embodiments, a reference measure is relied upon a distance from a concerning feature vector to a closed space wherein feature vectors without noises are gathered. Representing the closed space by a set of sample points, a distance to a nearest sample point is defined as the quality index.

15 In the following paragraphs, principle of quality index extraction is described first.

Feature vectors obtained without noises from high-grade pattern images are localized in a certain closed part of a space having the same dimensions with those of the feature vectors. An example of the closed part is denoted by Ω in FIG. 8 illustrating a space of the dimensions. Data samples of feature vectors having high-grade quality index without noises are represented by black dots in the closed space Ω .

25 When there are sufficient number n_s of the data samples in the closed space Ω , distances between neighboring feature vectors converge to zero. That is, following equation stands with any feature vector x in the closed space Ω .

$$\lim_{n \rightarrow \infty} \min_{y \in \Omega} \|x - y\| = 0 \quad (42)$$

Consider a feature vector X , originally to be in the closed space Ω when there is no noise, is extracted as another feature vector O of FIG. 8 from outside of the closed space Ω because of mingled noise vector N .

The quality index defined in the second embodiments is a distance from a sample point Y nearest to the concerning feature vector O , which is expressed as $\|Y - O\|$. This distance should be the same with the distance to the closed space Ω when there are sufficient number of sample points.

Hence, the distance to the closed space Ω can be approximated by obtaining a minimum value of distances to feature vectors in a database where sufficient number of feature vectors without noise are prepared.

Now, a concrete example of the second embodiments is described. In the second embodiments, following elements of FIG. 1 are modified, that is, the quality index extraction means 106 or 505, the confidence attribution means 107, the error distribution information storing means 105, and the error distribution information analyzing means 506, and other elements are left unchanged. Furthermore, in the first embodiments of FIG. 1 and FIG. 5, the quality index extraction means 106 or 505 is depicted to extract quality indexes directly from image data. However, in the second embodiments, the quality index extraction means 106 or 505 is supplied with feature vectors after condensed through the KLT by the vector transfer means 103 or 505.

FIG. 9 is a block diagram illustrating a quality index extraction means 90 according to the second embodiments, comprising a database 903 wherein a plurality of feature vectors without noise and pro-

cessed through the KLT are prepared, a distance calculation means 901 for calculating a distance between an input feature vector and the plurality of feature vectors prepared in the database 903, a distance revision means 902 for revising/retaining a minimum value among the distances calculated by the distance calculation means 901, and a control means 904 for controlling above elements of the quality index extraction means 90.

Now, operation of the quality index extraction means 90 of the second embodiments is described.

FIG. 10 is a flowchart illustrating processes performed in the quality index extraction means 90 of FIG. 9, comprising a feature vector distance calculation step 1001, a minimum distance revision step 1002 and a finish determination step 1003.

First, a distance, namely a similarity of an input feature vector to that in the database 903 is calculated (at step 1001).

In the database 903, the plurality of high-quality feature vectors are prepared processed through the KLT. Although the high-quality may be discriminated by way of expert's eye, it can be preferably discriminated automatically referring to standard deviation of errors among at least two feature vectors (after the KLT) taken from the same fingerprint. Sets of feature vectors obtained from the same pattern images giving the standard deviation of errors smaller than a threshold value are selected to be of the high-quality with few noises. As for the number of feature vectors, more than 10 thousands may be sufficient in the case of fingerprint.

The distance of the input feature vector is calculated according to the Euclidean distance represented by equation (4), for example.

The distance revision means 902 revises a retaining minimum value when the distance newly calculated is smaller than the retaining minimum value (at step 1002).

5 The control means controls the quality index extraction means 90 to repeat steps 1001 and 1002 until distance calculation of an input feature vector to all the feature vectors registered in the database 903 is finished (determined at step 1003). Thus, the distance of the input feature vector to the set of reference data can be calculated to be output as the quality index Q . In the second embodiments, the quality index
10 Q has a scalar value, different from the quality index having vector value of the first embodiments.

The second embodiment of the skin pattern feature analyzer prepares the error distribution table making use of the quality indexes Q thus extracted by the quality index extraction means 90 from a data
15 set having appropriate quality range. An error distribution information analyzing means similar to the error distribution information analyzing means 506 of FIG. 5 may calculate the standard deviation of the error values according to equation (40) or (41) regarding each component $Q_{i,j,l}$ has the same value $Q_{i,j}$ for each paired feature vectors $v_{i,1}$ and
20 $v_{i,2}$.

Here, the error distribution table is not necessary to be a 2-dimensional as illustrated in FIG. 4. The error distribution table of the second embodiments is sufficient to be 1-dimensional as illustrated in FIG. 11. An experimental result of the error distribution table of
25 FIG. 11 is shown as a graphic chart of FIG. 12 corresponding to that of FIG. 7

The skin pattern matching system of the second embodiment per-

forms skin pattern matching verification making use of the quality index Q obtained by the quality index extraction means 90. The skin pattern matching verification performed here is described also referring to FIG. 1.

5 Processings performed in the quality index extraction means 106 of FIG. 1 is executed by the quality index extraction means 90 in the second embodiment, whereto condensed feature vectors processed through the KLT are input from the vector transfer means 103, instead of source feature vectors input directly from the feature extraction
10 means 103 in the first embodiment.

 In the error distribution information storing means 106, the error distribution information is registered in a 1-dimensional error distribution table.

 The confidence attribution means 107 outputs the standard deviation of errors referring to the 1-dimensional error distribution table in
15 the quality index storing means 106 by accessing thereto with the scalar quality index Q obtained from the quality index extraction means 90 corresponding to concerning feature vector v .

 Other processings are performed in the same way with the first
20 embodiment, and duplicated descriptions are omitted.

 In the following paragraphs, third embodiments of the skin pattern matching system and the skin pattern feature analyzer is described, wherein a distance of a ridge line pattern to a reference pattern is adopted as the quality index.

25 FIG. 13 is a block diagram illustrating a configuration of the quality index extraction means 130 according to the third embodiments, comprising;

a first, a second and a third direction pattern storing means 1301, 1304 and 1306,

5 a distance calculation means 1302 for calculating distances between input ridge direction patterns stored in the first direction pattern storing means 1301 and affine transferred ridge direction patterns stored in the third direction pattern storing means 1306 referring to their confidences stored therewith, respectively,

10 a parameter revision means 1303 for determining whether the distance calculated by the distance calculation means 1302 is the shortest or not, and memorizing affine parameters when the distance is the shortest,

15 an affine transfer means 1305 for performing affine transfer of ridge direction patterns and their confidences stored in the first and the second direction pattern storing means 1301 and 1304, the obtained affine transformations being stored in the third direction pattern storing means 1306, and

a control means 1307 for controlling operation of each element of the quality index extraction means 130 including parameter control of the affine transfer.

20 FIG. 14 is a flowchart illustrating processes performed in the quality index extraction means 130 of FIG. 13, comprising an affine transfer step 1401, a distance calculation step 1402, a distance/affine parameter revision step 1403, and a finish determination step 1404.

25 Now, referring to FIG. 14, operation of the quality index extraction means 130 of FIG. 13 according to the third embodiment is described.

Ridge direction patterns $\theta(C)$ and their confidences $q(C)$ such as

previously described in connection with the first embodiment of the skin pattern matching system are input to the first direction pattern storing means 1301. In the second direction pattern storing means 1304, reference ridge direction patterns $\Theta(C')$ and their confidences $Q(C')$ are stored. The reference ridge direction patterns $\Theta(C')$ and their confidences $Q(C')$ are prepared, for example, by obtaining mean values of n (10 thousands, for example) sets of ridge direction patterns θ_i ($i = 1, 2, \dots, n$) according to following equations.

$$\Theta_x(C') = \frac{1}{n} \sum_{i=1}^n \cos(2\theta_i(C')) \quad (43)$$

$$\Theta_y(C') = \frac{1}{n} \sum_{i=1}^n \sin(2\theta_i(C')) \quad (44)$$

$$\Theta(C') = \frac{1}{2} \tan^{-1} \frac{\Theta_y(C')}{\Theta_x(C')} \quad (45)$$

$$Q(C') = \sqrt{\Theta_x(C')^2 + \Theta_y(C')^2} \quad (46)$$

The affine transfer means 1305 performs affine transfer (at step 1401) of direction patterns and their confidences of an input pattern image stored in the first direction pattern storing means 1301 using affine parameter sets each determined according to each ensemble of parallel/rotation displacement values ($\Delta x, \Delta y, \Delta \theta$) in a search range.

The affine transfer is well known and described also in pp. 423-429 of the previous "Handbook of Image Analysis". Hence, detailed explanation is omitted. However, it is to be noted here, in the affine transfer of the ridge direction pattern, that component values of the ridge direction patterns $\theta(C')$ are defined relatively to the coordinate system and they are variable when the coordinate system is such rotated as in the affine transfer, deferently from ordinary affine transfer of images. Hence, for the rotation $\Delta \theta$ of the coordinate system, $\Delta \theta$ is added to each component value of the ridge direction patterns $\theta(C')$.

The obtained affine transformations are registered in the third direction pattern storing means 1306. The size of the affine transformations to be stored in the third direction pattern storing means 1306 are adjusted to be the same with the source ridge direction patterns in the first direction pattern storing means 1301. Where there is no reference point, concerning confidence is set to be null. By preparing the reference ridge direction patterns $\Theta(C')$ and their confidences $Q(C')$ to be stored in the second direction pattern storing means 1304 to have larger sizes than ridge direction patterns of the input pattern image, parts having no reference point can be reduced and the transfer precision is improved.

As for the search range of the parallel/rotation displacement values $(\Delta x, \Delta y, \Delta \theta)$, it can be defined as follows, for example. When the ridge direction pattern $\theta(C')$ has a size of 16×16 , as in this case, nine values $-4, -3, \dots, +3, +4$ are assigned for both the parallel displacements Δx and Δy , and seven values $-30^\circ, -20^\circ, \dots, +20^\circ, +30^\circ$ for the rotation displacement $\Delta \theta$. Thus, $9 \times 9 \times 7 = 567$ displacement ensembles are obtained. Further, by applying the image center detection method disclosed in the Provisional Publication No. 271884/'89 beforehand mentioned, the search range can be reduced around the center of fingerprints for economizing computational time.

The distance calculation means 1302 calculate the distance D (at step 1402) according to following equation for each affine parameter set.

$$D = \frac{\sum_C q(C)^\gamma F(Q(C))^\gamma (|\theta_x(C) - F(\Theta_x(C))|^2 + |\theta_y(C) - F(\Theta_y(C))|^2)}{\sum_C q(C)^\gamma F(Q(C))^\gamma} \quad (47)$$

where,

$$\theta_x(C) = \cos(2\theta(C)) \quad (48)$$

$$\theta_y(C) = \sin(2\theta(C)) \quad (49)$$

Here, $F(*)$ represents the affine transformation of $*$, and γ is a parameter having a value 0.5, for example.

5 The parameter revision means 1303 checks whether the distance D is the shortest for a concerning input pattern image, and registers the distance and values of the affine parameter set giving the distance, when it is found to be the shortest (at step 1403).

10 The quality index extraction means 103 repeats steps 1401 to 1403 for each affine parameter set in the parallel/rotation displacement range calculating the distance D according to equation (47). When above repetition is finished (at step 1404) for a input pattern image, the revised minimum value of the distance D is output as the quality index.

15 The third embodiments of the skin pattern matching system and the skin pattern analyzer are embodied by comprising the above described quality index extraction means 130. The quality index output from the quality index extraction means 130 has a scalar value and may be treated in the same way with that obtained from the quality index extraction means 90 of FIG. 9 of the second embodiments of the invention, duplicated explanation being omitted.

20 Further, by performing affine transfer of each input pattern image making use of the affine parameter set giving the shortest distance thereof, the input pattern image can be aligned in the coordinate system. Therefore, the affine transfer may be applied also in the first 25 embodiments of the skin pattern matching system and the skin pattern analyzer for coordinate alignment of input data, that is, input image data or ridge direction data extracted as the feature vector.

Still further, the affine transfer is described to be performed each time with each affine parameter set in the search range of the parallel/rotation displacements. However, a database may be beforehand prepared, wherein affine transformation data of all components of the ridge direction patterns for all displacements in the search range are registered. Then, the quality index is extracted by calculating the distance to all the data registered in the database in the similar way with the quality index extraction means 90 of FIG. 9 of the second embodiments. By pre-performing such time consuming processes as the affine transfer, calculation time can be still reduced.

In the fourth embodiment of the skin pattern matching system, the fingerprint matching verification is performed making use of all or some of the three quality index extraction means 505, 90 and 130 heretofore described, and commonly available parts are jointly used.

FIG. 15 is a block diagram illustrating the fourth embodiment of the skin pattern matching system of the invention, wherein all the three quality index extraction means are applied.

Referring to FIG. 15, the skin pattern matching system of the fourth embodiment has a feature extraction section 151 for extracting feature data from skin pattern images, a database section 12 for storing and managing the feature data, a matching section 13 and a control section 14.

The database section 12, the matching section 13 and the control section 14 may have the same configuration with those of FIG. 1, and so, duplicated description is omitted.

The feature extraction section 151, which takes charge of outputting a feature vector and standard deviation of estimated errors of

an input skin pattern image data, comprises;

an image input means 1501 where image data of a skin pattern such as a fingerprint or a palm print are input,

5 a ridge direction extraction means 1502 for extracting a ridge direction pattern and its confidence from the image data input through the image input means 1501,

a center detection means 1507 for detecting center of the image data input through the image input means 1501,

10 a coordinate alignment means 1508 for performing coordinate alignment of the ridge direction pattern and its confidence extracted by the ridge direction extraction means 1502, and for calculating a first quality index according to conformity obtained along with the coordinate alignment,

15 - a principal component vector storing means 1503 wherein are prepared principle component vectors of distribution of vectors consisting of direction patterns processed by the coordinate alignment means 1508,

20 a vector transfer means 1504 for generating a feature vector by performing the KLT of the vector of the direction pattern processed by the coordinate alignment means 1508 making use of the principal component vectors prepared in the principal component vector storing means 1503,

25 a distance calculation means 1505 for obtaining a second quality index by calculating a minimum distance of the feature vector processed by the vector transfer means 1504 to a high-quality data set of feature vectors beforehand prepared,

a contribution calculation means 1506 for obtaining a third quality

index of each dimension of the feature vector from its confidence aligned by the coordinate alignment means 1508 and the principal component vectors,

5 a first error distribution information storing means 1513 wherein standard deviation of errors of the feature vectors corresponding to the first quality index is prepared in a first lookup table,

a second error distribution information storing means 1514 wherein standard deviation of errors of the feature vectors corresponding to the second quality index is prepared in a second lookup table,

10 a third error distribution information storing means 1515 wherein standard deviation of errors of the feature vectors corresponding to the third quality index is prepared in a third lookup table,

a first confidence attribution means 1509 for obtaining a first confidence value to be attributed to the feature vector by referring to the first lookup table accessed with the first quality index,

15 a second confidence attribution means 1510 for obtaining a second confidence value to be attributed to the feature vector by referring to the second lookup table accessed with the second quality index,

20 a third confidence attribution means 1511 for obtaining a third confidence value to be attributed to the feature vector by referring to the third lookup table accessed with the third quality index, and

a confidence estimation means 1512 for outputting a confidence estimation of the feature vector according to the first, the second and the third confidence value.

25 Now, operation of the fourth embodiment of the skin pattern matching system will be described referring to FIG. 15.

Each of the above means except for the confidence estimation

means 1512 can be realized by applying each corresponding means heretofore described in connection with the first to the third embodiments. Hence, these means other than the confidence estimation means 1512 are briefly described, here.

5 The ridge direction extraction means 1502 extracts the ridge direction pattern and its confidence in the same way with the feature vector extraction means 101 and the quality index extraction means 106 of FIG. 1, such as disclosed in the Provisional Publication No. 7079/'96.

10 The coordinate alignment means 1508 outputs the first confidence indication obtained by calculating a distance of the ridge direction pattern to a reference pattern in the same way with the quality index extraction means 130 of FIG. 13, where the distance is a minimum value of D of equation (47) obtained when the ridge direction pattern is most
15 fitted to the reference pattern by positioning the ridge direction pattern to the reference pattern. Here, search range of the parallel/rotation displacement is set around the center of the fingerprint detected by the center detection means 1507 such as disclosed in the Provisional Publication No. 271884/'89 beforehand mentioned. Further, position
20 of the ridge direction pattern and its confidence are normalized here by performing the affine transfer using the affine parameter set giving the highest conformity. The coordinate alignment means 1508 outputs the ridge direction pattern as a vector value expressed by equation (22) referred to in connection with the first embodiments.

25 The vector transfer means 1504 performs the KLT of the vector output of the coordinate alignment means 1508 for outputting a feature vector according to equation (23) referring to the principal component

vectors prepared in the principal component vector storing means 1503, in the same way with the vector transfer means 103 of FIG. 1.

5 The distance calculation means 1505 outputs the second quality index obtained by calculating minimum distance of the feature vector to the high-quality data set in the same way with the quality index extraction means 90 of FIG. 9 beforehand described in connection with the second embodiments.

10 The contribution calculation means 1506 outputs the third quality index by calculating confidence value of the ridge direction pattern for each component of the feature vector according to equation (25), in the same way with the quality index extraction means 106 of FIG. 1 described in connection with the first embodiments.

15 The first, the second and the third confidence attribution means 1509, 1510 and 1511 output the first, the second and the third confidence value, respectively, for each component of the feature vector, obtained by referring to respective lookup table accessing with respective quality index thus obtained of the feature vector.

20 Contents of each of the first, second and the third lookup tables in the first, the second and the third error distribution information storing means 1513, 1514 and 1515 can be prepared in the same way as described in connection with the third, the second or the first embodiments, respectively, by analyzing respective error distribution obtained through the coordinate alignment means 1508, the distance calculation means 1505 or the contribution calculation means 1506, respectively, 25 from a data set of fingerprint images having an appropriate quality range.

The first, the second and the third confidence value being denoted

by three vectors $^1\sigma$, $^2\sigma$ and $^3\sigma$, respectively, the confidence estimation means 1512 estimates the confidence estimation $\bar{\sigma}$ from the three vectors according to following equation.

$$\bar{\sigma}_i = \sqrt{\sum_{j=1}^3 {}^j\sigma_i^2} \quad (50)$$

5 Here, $\bar{\sigma}_i$ represents an i -th component of the confidence estimation $\bar{\sigma}$, and ${}^j\sigma_i$ represents the i -th component of the first to the third confidence value ${}^j\sigma$.

Or, otherwise, the confidence estimation $\bar{\sigma}$ may be estimated as follows instead of above equation.

$$10 \quad \bar{\sigma}_i = \max_j {}^j\sigma_i \quad (51)$$

The confidence estimation means 1512 outputs the feature vector processed through the KLT and its confidence estimation $\bar{\sigma}$ as output of the feature extraction section 151.

By applying the confidence estimation thus integrated from more
15 than one quality index value, a better result can be obtained, demerits of each individual quality index being compensated, according to the fourth embodiment.

In the following paragraphs, a fifth embodiment of the skin pattern matching system of the invention will be described, wherein Fourier
20 transformation of the skin pattern image is applied to the feature vector extraction thereof.

First, principle of the fifth embodiment is explained referring to a schematic diagram of FIG. 16.

In representatives of the fingerprint pattern, there are the Arch,
25 the Loop, the Whorl and so on. These patterns have their own forms, and hence, 2-dimensional power spectrums of Fourier transformation thereof have their own features, as illustrated in FIG. 16.

Referring to FIG. 16, a1, b1 and c1 represent the Arch, the Loop and the Whorl, respectively, a2, b2 and c2 representing characteristic parts of the Fourier power spectrums thereof (direct current, or zero frequency component, being set to their centers).

5 In each of the Fourier power spectrums a2, b2 and c2, lower frequency components, that is, inner patterns, owe to uneven stamping, stamping pressure or background of the fingerprint image and they are not significant for discriminating the fingerprint. The spectrum lines of horizontal and vertical zero frequency, that is, xy -coordinate axis-like
10 lines, represent noises owing to discontinuity at end lines of the image, and have no reference with the fingerprint discrimination.

On the other hand, the higher frequency components, that is, the outer patterns such as \subset -like pattern of the spectrum a2 or a ring
- pattern of the spectrum c2, represent features concerning fingerprint
15 ridge lines, and substantially show following three characteristics.

1. Radial distance ρ of spectrum distribution center from the direct current component represents mean value of the ridge line pitch;
2. Rotation direction ϕ of the spectrum distribution center represents whether the fingerprint has right inclination or left inclination.
- 20 3. Whether the spectrum distribution is peak-like or ring-like corresponds to arch-like or whorl-like of the fingerprint.

Therefore, by sampling most characteristic frequency band from the Fourier power spectrum of the fingerprint pattern by filtering out unnecessary high frequency components and low frequency compo-
25 nents, a feature value representing a whole fingerprint pattern can be extracted.

Column charts a3, b3 and c3 of FIG. 16 schematically illustrate

feature values of respective fingerprint patterns a1, b1 and c1 sampled with a fixed frequency band, namely, with a fixed radial distance ρ around the direct current ($0 \leq \phi < \pi$).

Now, the fifth embodiment of the skin pattern matching system of the invention based on the above principle is described.

FIG. 17 is a block diagram illustrating a feature vector extraction means of the fifth embodiment corresponding the feature vector extraction means 102 of FIG. 1, comprising a Fourier transfer means 1701 for performing Fourier transfer of a fingerprint image, a power calculation means 1702 for calculating Fourier power spectrum of the Fourier transformation output of the Fourier transfer means 1701, a filtering means 1703 for filtering the Fourier power spectrum, and a sampling means 1704 for sampling characteristic spectrum components from output of the filtering means 1703 to be output as the feature vector.

The skin pattern matching system of the fifth embodiment comprising the above feature vector extraction means operates as follows.

The Fourier transfer means 1701 performs digital Fourier transfer of the input 2-dimensional pattern image. As to the digital Fourier transfer, it is well known and also described in pp. 5-11 of the "Handbook of Image Analysis", explanation thereof being omitted. Here, the fingerprint image is expressed by $h(x, y)$, Fourier transfer thereof by $F(h(x, y))$ and Fourier components transferred by the Fourier transfer means 1701 by $H(u, v)$, where (x, y) represents coordinates in the real space and (u, v) represents corresponding coordinates in the frequency domain. Hence, manipulation performed by the Fourier transfer means 1701 is expressed by following equation.

$$H(u, v) = F(h(x, y)) \quad (52)$$

The power calculation means 1702 calculate absolute value $\|H(u, v)\|$ of the Fourier components $H(u, v)$, obtained as a complex number, as follows.

$$\|H(u, v)\| = \sqrt{\Re(H(u, v))^2 + \Im(H(u, v))^2}, \quad (53)$$

5 where $\Re(H(u, v))$ and $\Im(H(u, v))$ represent real part and imaginary part of the Fourier components $H(u, v)$, respectively.

The filtering means 1703 performs, for example, convolution operation (Gaussian filtering) making use of well known 2-dimensional Gaussian function $G(u, v; \sigma)$, for filtering the Fourier power spectrum
10 $\|H(u, v)\|$ output of the Fourier transfer means 1702, as follows when filtered image data is expressed by $J(u, v)$.

$$J(u, v) = \sum_p \sum_q G(p, q; \sigma) \|H(u + p, v + q)\| \quad (54)$$

$$G(u, v; \sigma) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{u^2 + v^2}{2\sigma^2}\right) \quad (55)$$

15 Here, the parameter σ of the 2-dimensional Gaussian function may be set to be about 3 to 7 pixels (counted in the frequency domain), when the input image has 512×512 pixels.

The sampling means 1704 samples pixel data of the filtered Fourier power spectrum $J(u, v)$ in a frequency band defined by following equations at an appropriate interval d , as illustrated in a schematic diagram
20 of FIG. 18.

$$r_1 < u^2 + v^2 < r_2 \quad (56)$$

$$v \geq 0 \quad (57)$$

25 In an example of the embodiment, a feature vector f is obtained from near 200 samples by setting $r_1 = 20$, $r_2 = 80$ and the sampling interval d as 10×10 .

Size of the feature vector $\|f\|$ reflects signal intensity of the object

fingerprint image, and so, can be used as the quality index of the feature vector f .

Thus, the feature vector and its quality index are obtained in the fifth embodiment of the skin pattern matching system. Other
5 component than the feature vector extraction means may be configured in the same way with the first to the fourth embodiments heretofore described, by applying the above feature vector extraction means to the feature vector extraction means 102 of FIG. 1, for example.

In the embodiments heretofore described, the feature vector pro-
10 cessed through the KLT is applied for the skin pattern matching verification or the skin pattern analysis. However, the scope of this invention of the image feature analyzer and the image matching system is not limited in the feature vector processed through the KLT. As an example without the KLT, an embodiment making use of feature val-
15 ues defined by singular points such as the cores and the deltas in the fingerprint will be described in the following paragraphs.

Maximum number of the cores and the deltas in the fingerprint is usually found in the Whorl, wherein are found four singular points, two cores and two deltas. There can be defined $4C_2 = 6$ segments
20 connecting these four singular points. Therefore, 12 feature values can be obtained, that is, 6 lengths of the 6 segments and 6 numbers of ridge lines crossing the 6 segments. Further, each of the 12 feature value has each confidence value, as described in Uchida et al., previously referred to. These confidence values can be used for the quality index (and
25 called the quality index, hereafter).

Therefore, following vectors can be defined from these feature values and their quality indexes.

$$\text{feature value: } v = \begin{pmatrix} v_1 \\ v_2 \\ \vdots \\ v_i \\ \vdots \\ v_{12} \end{pmatrix} \quad (58)$$

$$\text{quality index: } q = \begin{pmatrix} q_1 \\ q_2 \\ \vdots \\ q_i \\ \vdots \\ q_{12} \end{pmatrix} \quad (59)$$

Here, when there are found but less than four singular points as in the Loop, or when some singular points are failed to be detected, corresponding components of the quality vector v are substituted with a value out of bounds (-1 , for example, when the confidence value is 0 to 1).

FIG. 19 is a block diagram illustrating a basic configuration of the sixth embodiment of the skin pattern matching system, wherein the vector transfer means 103 and the principal component vector storing means 104 are omitted compared to the skin pattern matching system of FIG. 1.

Referring to FIG. 19, the sixth embodiment of the skin pattern matching system has,

a feature extraction section 191 comprising an image input means 1901, a feature vector extraction means 1902, a error distribution information storing means 1904 and a confidence attribution means 1905,

a database section 12 comprising a data storing means 109 wherein prepared the feature data extracted by the feature extraction section 191, and a database management means 108 taking charge of reference or registration of the feature data in the data storing means 109,

5 a matching section 13 for performing the skin pattern matching verification to output matching results comprising a similarity calculation means 110 for calculating a similarity of the feature data supplied from the feature extraction means 191 to each of the feature data stored in the database section 12, and a determination means 111 for determining
10 mining accordance/discordance from the similarity calculated by the similarity calculation means 110, and

a control section 14 for controlling each of the above elements.

The database management section 12, the matching section 13 and the control section 14 operates in the same way with those of FIG.
15 1, and so, operation of the feature extraction section 191 is described, here.

The feature vector extraction means 1902 extracts the feature vector v according to equation (58) as above described referring to the singular points of the cores and deltas.

20 The quality index extraction means 1904 extracts the quality vector q according to equation (59).

In the error distribution information analyzing means 1903, there is prepared a lookup table wherein registered standard deviation of errors $\sigma_i(q_i)$ of components v_i of each dimension of the feature vector
25 v . When the quality index value is that of out of bound, -1 , because of missing data, a fixed value is registered there. As for the fixed value, it is sufficient to be more than 1000 times of the ordinary standard

deviation, or zero when inverse standard deviation is registered in the lookup table.

The confidence attribution means 1905 outputs a confidence vector σ by referring to the lookup table in the error distribution information analyzing means 1903 by accessing thereto with the quality vector q .

Then, the same procedure follows as beforehand described in connection with the first embodiment of the skin pattern matching system.

The lookup table in the error distribution information analyzing means 1903 is prepared by a fourth embodiment of the skin pattern feature analyzer, whereof a block diagram is illustrated in FIG. 20.

Referring to FIG. 20, the skin pattern analyzer of the fourth embodiment comprises a feature vector extraction means 2001, a quality index extraction means 2002 and an error distribution information analyzing means 2003.

The feature vector extraction means 2001 extracts feature vectors v from a data set of a plurality, 10 thousands, for example, of paired images according to equation (58). The quality index extraction means 2002 extracts quality vectors q from the data set according to equation (59).

The error distribution information analyzing means 2003 prepares a 2-dimensional lookup table by calculating error distribution for each quantized quality index value of each dimension, analyzing the error distribution in the same way with the error distribution information analyzing means 506 of FIG. 5. Here, data corresponding to the quality index value out of bounds, -1 , are omitted from the accumulation operation regarded as defect data.

Thus, the skin pattern feature analyzer and the skin pattern

matching system of high-precision can be embodied even without the KLT.

In the embodiments heretofore described of the invention, matching of one fingerprint is discussed. However, it can be easily understood
5 that the present invention can be applied to the Ten Print Card.

When applying to the Ten Print Card, the operation for one finger as heretofore described may be repeated ten times for each of ten fingers, preparing data of feature vectors and confidence vectors for ten fingers in the database section and so on.

10 Further, the condensed feature vectors (5-dimensional, for example,) processed through the KLT of ten fingers may be integrated into a 50-dimensional feature vector, and may be condensed again through the KLT. Applying upper one or two dimensions thereof, the data amount to be treated of ten fingers may be still reduced. As for con-
15 fidence value in the case, equation (25) can be applied by obtaining quality value $q(C)$ from confidence vector of each finger, for example.

Thus, by repeating the KLT for whole card data, discrimination performance can be still improved without increasing dimension number of feature values. Further, treating the whole card data is especially
20 effective in the case matching verification operation is finished when similarity distance accumulation attains to a threshold value, since discordant card data can be rejected in earlier stage of the operation by treating the whole card data at the same time.

Heretofore, the present invention is described mainly in connection
25 with embodiments applied to fingerprint identification. However, it goes without saying that there are many applications or modifications in the scope of the invention. For example, the invention can be applied

just the same way to the palm print identification. In the palm print, there are four delta parts at each finger base except the thumb, as illustrated in Fig. 21. Therefore, by cutting out 512 x 512 pixel data of 500 dpi of the deltas from a paper stamped with a palm print, they can be treated as a four fingerprint card, instead of the Ten Print Card.

Each feature disclosed in this specification (which term includes the claims) and/or shown in the drawings may be incorporated in the invention independently of other disclosed and/or illustrated features.

The text of the abstract filed herewith is repeated here as part of the specification:

For providing an efficient image pattern matching system, an image feature extractor (11) of the invention comprises a feature vector extraction means (101) for extracting a feature vector from the pattern image, a quality index extraction means (106) for extracting quality index information of the pattern image, an error distribution information representing correlation between error distribution of the feature vector and the quality index information is prepared, and a confidence attribution means (108) for obtaining confidence estimation information referring to the error distribution information retrieved with the quality index information. The image feature analyzer (51) prepares the error distribution information. An image feature matching system identifies feature information of an image pattern extracted by the image feature extractor (11) by comparing it to registered feature information.

CLAIMS:

1. A system for collating images comprising:
 - means for deriving a feature value for the features of each image;
 - means for deriving a quality index value for the features of each image;
 - means for determining errors for the feature values in which said errors are adaptively measured according to the quality index of the features of each image;
 - and
 - means for determining the extent of ectypography between features of each image.
2. A system for collating images according to claim 1, in which said means to determine the extent of ectypography between features of each image comprises:
 - means for considering the confidence of the feature values between image features;
 - means for analysing the two images by considering the confidence of the feature values and for referring to the errors for the feature values for the two image features; and
 - means to refer to said errors for the feature values to determine if one feature is an ectype of a feature in another image.
3. An system according to claim 1 or 2, further comprising
 - an image feature extractor means;
 - a index quality extraction means for extracting the quality of the index information of a pattern image;
 - an image feature analyzer which prepares error distribution information representing correlation between error distribution of the feature vector and the quality index information;
 - a confidence attribution means for obtaining confidence estimation information referring to the error distribution information retrieved with the quality

index information; and

which identifies the feature information of an image pattern extracted by the image feature extractor by comparing it to registered feature information.

4. An image feature extractor for a system according to any preceding claim, wherein said image feature extractor outputs a feature information data set of a pattern image including data of a feature vector of the pattern image and confidence estimation information of the feature vector attributed to each component of the feature vector, said image feature extractor comprising;

a feature vector extraction means for extracting the feature vector from the pattern image;

at least one quality index extraction means for extracting quality index information of the pattern image;

at least one error distribution storing means, corresponding to each of said quality index extraction means, wherein error distribution information is prepared, said error distribution information representing correlation between the error distribution of a plurality of feature vectors and the quality index information corresponding to said quality feature vectors;

a confidence attribution means, each corresponding to each of said error storing means for obtaining confidence information referring to said error distribution information; and

a confidence estimation means for providing confidence estimation information.

5. An image feature extractor according to claim 4, wherein if only one quality index extraction means is provided, said confidence information is output as said confidence estimation information; and if a plurality of quality index extraction means is provided, said confidence estimation information is provided by integrating said confidence information obtained by each of said confidence attribution means.

6. An image feature extractor for a system according to any of claims 1, 2 or 3, for outputting a feature information data set of a pattern image including data of a feature vector of the pattern image and confidence estimation information of the feature vector attributed to each component of the feature vector, said image feature extractor comprising:

a feature vector extraction means for extracting the feature vector from the pattern image;

at least one quality index extraction means for extracting quality index information of the pattern image;

error distribution information storing means, each corresponding to each of said quality index extraction means, wherein error distribution information is prepared, and represents the correlation between the error distribution of a plurality of feature vectors and the quality index information corresponding to said plurality of feature vectors; and

confidence attribution means, each corresponding to each of said error distribution information storing means for obtaining confidence information referring to said error distribution information prepared in on of said error distribution storing means by way of said quality index information, said confidence information being output as the confidence estimation if only one quality index extraction means is provided and if a plurality of quality index extraction means are provided, said confidence estimation information is provided by integrating said confidence information obtained by each of said confidence attribution means.

7. An image feature analyzer for a system according to any of claims 1, 2 or 3, wherein said image feature analyzer obtains error distribution information representing correlation between the error distribution of a plurality of feature vectors and the quality index information corresponding to said plurality of feature vectors, said image feature analyzer comprising:

a feature vector extraction means for extracting the plurality of feature

vectors from pattern images;

an index quality extraction means for extracting the quality of the index information of the pattern image; and

a error distribution information analysing means for calculating the error distribution information from the error distributed among each feature vector set of the plurality of feature vectors and a value of the quality index information of each feature vector belonging to each feature vector set, said feature vector sets comprising feature vectors extracted from a plurality of pattern images of the same pattern.

8. An image collating system according to claim 1, in which said means for determining the extent of ectypography between image features is performed using a feature information data set of an image pattern including a feature vector of the image pattern and confidence information of the feature vector attributed to each component of the feature vector; said image collating system further comprising:

a database section wherein the feature information data set of each
of a plurality of pattern images is registered; and

a collating section to determine the degree of ectypography between the pattern

10 image by discriminating accordance/discordance of the
feature information data set of the pattern image with each of
the feature information data set registered in said database
section according to distance between two feature vectors each
included in respective feature information data set calculated
15 in consideration of the confidence information of the two fea-
ture vectors.

9. The image feature extractor recited in claim 6, said feature
vector extraction means comprising a primary feature vector extraction
means for extracting the feature vector of the pattern image of a skin
pattern by extracting ridge direction information of each sub-region of
5 the pattern image.

10. The image feature extractor recited in claim 6, said feature
vector extraction means comprising a primary feature vector extraction
means for extracting the feature vector from the pattern image of a
fingerprint pattern by extracting information of distances and ridge
5 line numbers between every two of singular points of the fingerprint
pattern.

11. The image feature extractor recited in claim 6, said feature
vector extraction means comprising a primary feature vector extraction
means for extracting the feature vector from the pattern image by
sampling discrete Fourier power spectrums in a certain frequency band,
5 said discrete Fourier power spectrums being obtained by performing
discrete Fourier transfer of said pattern image.

12. The image feature extractor recited in claim 9 or claim 10, said feature vector extraction means further comprising at least one vector transfer means each transferring the feature vector making use of a parameter set.

13. The image feature extractor recited in claim 12, one of said vector transfer means transferring the feature vector making use of a parameter set comprising at least one of primary principal component vectors of distribution of feature vectors each obtained from
5 a data set of a plurality of pattern images in the same way with the feature vector.

14. The image feature extractor recited in claim 12, one of said vector transfer means performing affine transfer of the feature vector making use of each of a plurality of parameter set defined in a certain search range and outputting an affine transformation of the
5 feature vector giving a minimum distance to a reference feature vector.

15. The image feature extractor recited in claim 11, said feature vector extraction means further comprising a vector transfer means for transferring the feature vector making use of a parameter set comprising at least one of primary principal component vectors of distribution
5 of feature vectors each obtained from a data set of a plurality of pattern images in the same way with the feature vector.

16. The image feature extractor recited in claim 14, one of said at least one quality index extraction means extracting said quality index information according to said minimum distance.

17. The image feature extractor recited in claim 6; one of said quality index extraction means extracting said quality index information according to a minimum value among distances of the

feature vector to a set of reference feature vectors each obtained from
5 a high-quality pattern image in the same way with the feature vector.

18. The image feature extractor recited in claim 9, one of said at least one quality index extraction means extracting said quality index information according to confidence of said ridge direction information of each sub-region of the pattern image.

19. The image feature analyzer recited in claim 7, said feature vector extraction means extracting each of the plurality of feature vectors from each of the pattern images of skin patterns by extracting ridge direction information of each sub-region of respective each of the
5 pattern images.

20. The image feature analyzer recited in claim 7, said feature vector extraction means extracting each of the plurality of feature vectors from each of the pattern images of fingerprint patterns by extracting information of distances and ridge line numbers between every two of
5 singular points of respective each of the plurality of fingerprint patterns.

21. The image feature analyzer recited in claim 7, said feature vector extraction means extracting each of the plurality of feature vectors from each of the pattern images by sampling discrete Fourier power spectrums in a certain frequency band, said discrete Fourier power
5 spectrums being obtained by performing discrete Fourier transfer of respective each of said pattern images.

22. The image feature analyzer recited in claim 19, or claim 20, said feature vector extraction means further comprising at least one vector transfer means each transferring the plurality of feature vectors making use of a parameter set.

23. The image feature analyzer recited in claim 22, one of said at least one vector transfer means transferring the plurality of feature vectors making use of a parameter set comprising at least one of primary principal component vectors of distribution of feature vectors each obtained from a data set of a plurality of pattern images in the same way with the plurality of the feature vector.

24. The image feature analyzer recited in claim 22, one of said at least one vector transfer means performing affine transfer of the plurality of feature vectors making use of each of a plurality of parameter set defined in a certain search range and outputting an affine transformation of each of the plurality of feature vectors giving a minimum distance to a reference feature vector.

25. The image feature analyzer recited in claim 21, said feature vector extraction means further comprising a vector transfer means for transferring the plurality of feature vectors making use of a parameter set comprising at least one of primary principal component vectors of distribution of feature vectors each obtained from a data set of a plurality of pattern images in the same way with the plurality of feature vectors.

26. The image feature analyzer recited in claim 24, said quality index extraction means extracting said quality index information according to said minimum distance.

27. The image feature analyzer recited in claim 7, said quality index extraction means extracting said quality index information according to a minimum value among distances of each of the plurality of feature vectors to a set of reference feature vectors each obtained from a high-quality pattern image in the same way with the plurality

of feature vectors.

28. The image feature analyzer recited in claim 19, said quality index extraction means extracting said quality index information according to confidence of said ridge direction information of each sub-region of said pattern images.

29. An image feature collating system
making use of a feature information data set taken from a person
including a feature vector and confidence information of the feature
vector attributed to each component of the feature vector; said image
5 collating system comprising a database section wherein the feature
information data set of each of a plurality of persons is registered,
and a collating section for identifying the person by discriminating accordance/discordance of the feature information data set of the person
to each of feature information data sets registered in said database section
10 according to distance between two feature vectors each included
in respective feature information data set calculated in consideration
of the confidence information of the two feature vectors, wherein:

15 said feature vector included in each of the feature information
data set taken from the person and said feature information
data sets prepared in said database section is obtained through
Karhunen Loève transfer of more than one feature vector each
obtained through Karhunen Loève transfer of a feature vector
extracted from a skin pattern image of a different fixed part of
20 each respective person.

30. A method for collating images comprising the steps of:
determining feature values for image features;
deriving quality index values for image features; and
determining the extent of ectypography between each image by considering the confidence between the features of each image and referring to the errors for the feature values for the two images wherein said errors are adaptively measured according to the quality index of the features of the images.
31. A method of or apparatus for collating images and determining the extent of ectypography between images substantially as described hereinbefore and as illustrated by the accompanying drawings.



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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

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Other: Online:WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	EP 0220032 A2 (PALANTIR), see abstract	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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